Ontario

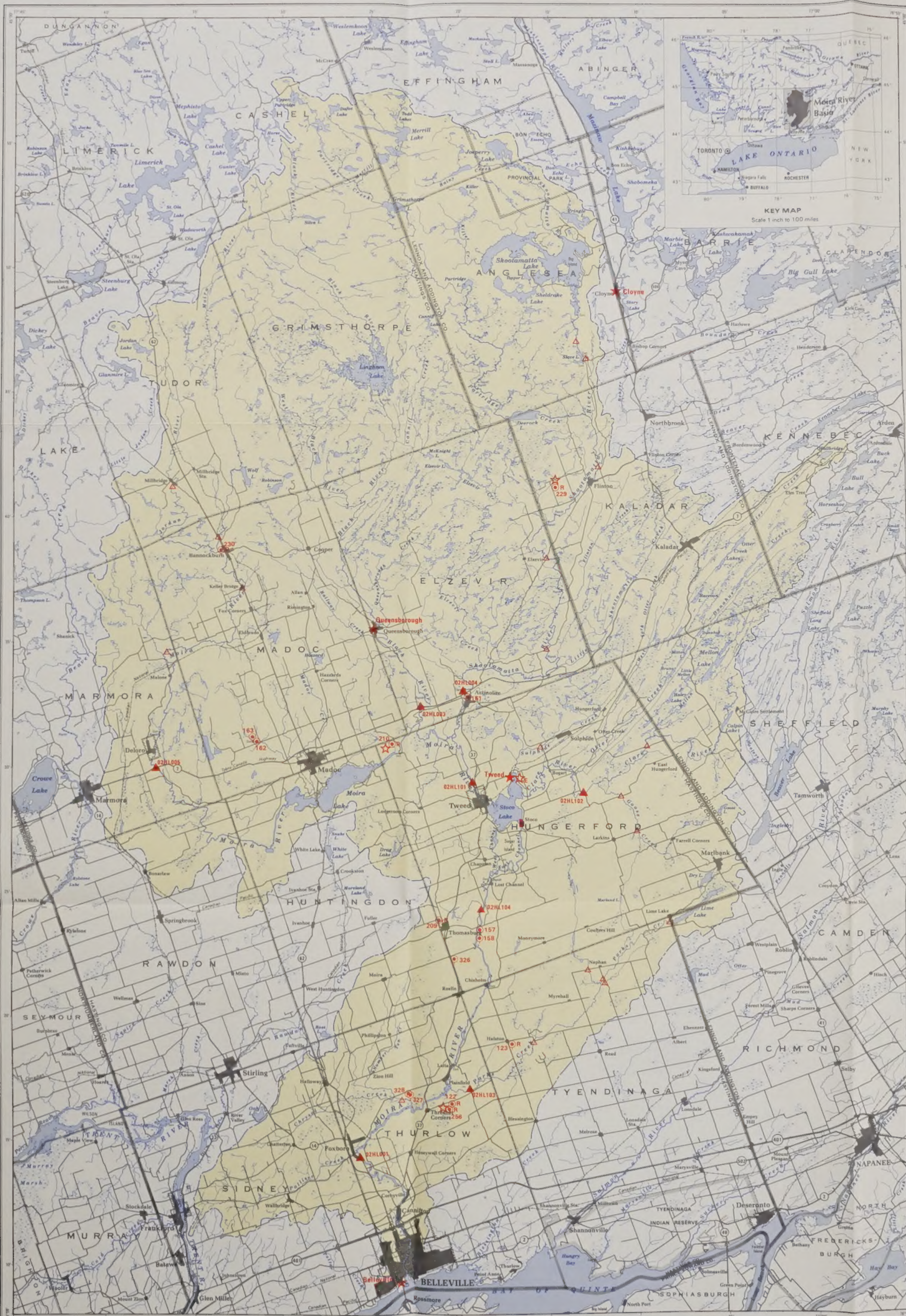
Ministry of the Environment

Hon. George A. Kerr, *Minister*
Everett Biggs, *Deputy Minister*

Water Resources Report 6

Water Resources of the Moira River Drainage Basin


QUEBEC
OTTAWA
LAKE ONTARIO
TORONTO
MISSISSAUGA
HAMILTON
ROCHESTER
BUFFALO
LAKE ERIE
NEW YORK
Moira River Drainage Basin
KEY MAP
Scale 1 inch to 50 miles
Black River Sub-Basin
Area 155 sq.mi.
Stream length 37 mi.
Avg. streambed gradient 16 ft./mi.
Skootamatta River Sub-Basin
Area 275 sq.mi.
Stream length 46 mi.
Avg. streambed gradient 14 ft./mi.
Moira River Sub-Basin above Deloro
Area 119 sq.mi.
Stream length 35 mi.
Avg. streambed gradient 13 ft./mi.
Clare River Sub-Basin
Area 117 sq.mi.
Stream length 26 mi.
Avg. streambed gradient 6 ft./mi.
Moira River Sub-Basin below Deloro
Area 268 sq.mi.
Stream length 37 mi.
Avg. streambed gradient 6 ft./mi.
Chrysal Creek Sub-Basin
Area 49 sq.mi.
Stream length 9 mi.
Avg. streambed gradient 34 ft./mi.
Parks Creek Sub-Basin
Area 77 sq.mi.
Stream length 20 mi.
Avg. streambed gradient 13 ft./mi.
MOIRA RIVER BASIN
Area 1060 sq.mi.
Stream length 92 mi.
Avg. streambed gradient 9 ft./mi.
Madoc
Marmora
Tweed
Stoco Lake
Moira Lake
Stirling
Frankford
BELLEVILLE
BAY OF QUINTE
Big Gull Lake
Limerick Lake
Skootamatta Lake
Mazinaw Lake
LEGEND
SYMBOLS
ELEVATION TINTS
Metres
Feet
488 1600
457 1500
427 1400
396 1300
366 1200
335 1100
305 1000
274 900
244 800
213 700
183 600
152 500
122 400
91 300
61 200
Drainage basin boundary
Sub-basin boundary
Intermittent lake
Marsh or swamp
Dam
Falls, rapids
Major population centre
Topographic contour, interval 50 feet
Note: All elevations in feet above mean sea level.
SOURCES OF INFORMATION
Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic Series, with additional information from staff surveys and from aerial photographs.
Cartography by C. Merritt, 1972.
To accompany Water Resources Report 6
Ontario
MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch
MOIRA RIVER DRAINAGE BASIN
MAP 1
PHYSIOGRAPHY AND SUB-BASINS
Scale 1:100,000
1 inch equals 1.58 miles
Miles
Kilometres
MAP 2762-1
Transverse Mercator Projection



Printed 1973

Transverse Mercator Projection

LEGEND

Meteorological station, permanent
Tweed — Stations operated and data published by Environment Canada. Record at Tweed intermittent since April1925; record at Belleville since January 1866; record at Cloyne since November 1967; record at Queensborough, 1914 to 1946

Meteorological station, seasonal
Precipitation measurements only, recording gauge operated by the Ontario Ministry of the Environment from May to October, 1969 and 1970

Evaporation station, seasonal
E — Class A evaporation pan, maximum and minimum air and water thermometers, totalizing anemometer, and standard rain gauge; operated by the Ontario Ministry of the Environment from August to October, 1969, and from May to October 1970

Streamflow gauging station, recording gauge
Details in Table below

Streamflow gauging station, periodic measurement
Established by the Ontario Ministry of the Environment, measurements from May to September 1969

Lake-level gauging station, recording
Operated by the Ontario Ministry of the Environment, record since July 1969

Observation well in bedrock, recording gauge
R — Operated by the Ontario Ministry of the Environment; 123, record since February 1965; 209, record since November 1967; 230, record since May 1969; 256, record since June 1970

Observation well in bedrock, periodic measurement
Operated by the Ontario Ministry of the Environment; 158, 161, and 163, record since September 1965; 326 and 327, record since December 1969

Observation well in overburden, periodic measurement
R — Operated by the Ontario Ministry of the Environment; 157, record since July 1965; 158 and 162, record since September 1965; 328, record since December 1969

Observation well in bedrock, recording gauge
Operated by the Ontario Ministry of the Environment; 123, record since February 1965; 209, record since November 1967; 230, record since May 1969; 256, record since June 1970

Details of Streamflow Gauging Stations

Station Number	Stream	Drainage Area (sq. mi.)	Period of Record	Streamflow: Minimum Daily (cfs)	Streamflow: Mean Annual (cfs)	Streamflow: Maximum Daily (cfs)	Regulation	Remarks
02HL001	Moira River near Foxboro	1040	Oct. 1915 to present*	15.0	1040	12,400	During summer	Records are excellent. Operated by Environment Canada
02HL003	Black River near Actinolite	155	July 1955 to present*	0	153	2,200	During summer	Records are excellent during open-water periods and good during ice periods. Operated by Environment Canada
02HL004	Skootamatta River near Actinolite	275	July 1955 to present*	0.8	201	2,660	During summer	Records are good to excellent during open-water periods and fair to good during ice periods. Operated by Environment Canada
02HL005	Moira River near Deloro	119	Aug. 1965 to present*	0.3	120	1,160	None	Records are excellent during open-water periods and good during ice periods. Operated by Environment Canada
02HL101	Moira River at Tweed	684	Oct. 1968 to present*	30.5	—	3,890	During summer	Operated by the Ontario Ministry of the Environment
02HL102	Clare River near Bogart	62	Oct. 1968 to present*	0.1	—	575	None	Operated by the Ontario Ministry of the Environment
02HL103	Parks Creek near Latta	77	Oct. 1968 to present*	2.3	—	550	During summer	Operated by the Ontario Ministry of the Environment
02HL104	Moira River near Thomasburg	854	Jan. 1969 to present*	25.0	—	6,170	During summer	Operated by the Ontario Ministry of the Environment

*present — as of December 31, 1970

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series, with additional information from staff surveys and from aerial photographs.

Cartography by C. Merritt, 1972

To accompany Water Resources Report 6

Ontario
MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch

WATER RESOURCES SURVEY
MOIRA RIVER DRAINAGE BASIN

MAP 2

HYDROMETRIC STATIONS

Scale 1:200,000

1 inch equals 3.16 miles

1 0 2 4 6 8 10
Miles

1 0 2 4 6 8 10 12 14
Kilometres

MAP 2752-2

LEGEND

PALAEOZOIC

ORDOVICIAN

Trenton Group: blue, fine crystalline limestone and grey shale

Black River Group: brown to grey, fine crystalline lithographic limestone and calcarenitic limestone

× SL Outcrop of Shadow Lake Formation: red and green shale; sandstone arkose

PRECAMBRIAN

Plutonic Rocks: granite, syenite, granitic rocks, diorite, gabbro, anorthosite, metagabbro, amphibolite

Metasedimentary Rocks: paragneiss, pellitic schists and gneisses, marble, lime silicates, skarn, para-amphibolite, biotite-amphibole schists and gneisses

Metavolcanic Rocks: basic volcanics, greenstone, pillow lava, amphibolite

SYMBOLS

Geological boundary, assumed

600 Bedrock surface contour, interval 50 feet (southern part only)

SOURCES OF INFORMATION

Bedrock geology and topography by U. Sibul 1970, on the basis of water-well records assembled by the Ministry of the Environment and the following geologic reports:

Hewitt, D. F., 1964, Geological notes for maps 2053 and 2054 Madoc-Gananoque area; ODM Geol. Circ. No. 12.

——————, 1968, Geology of Madoc Twp. and the north part of Huntingdon Twp. ODM Geol. Rept. 73.

Liberty, B. A., 1960, Belleville and Wellington map areas, Ontario; GSC Paper 60-31.

——————, 1963, Geology of Tweed, Kaladar and Bannockburn map areas, Ontario, with special emphasis on Middle-Ordovician stratigraphy; GSC Paper 63-14.

Sanford, D.V., 1961, Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; GSC Paper 60-26.

Winder, C. G., 1955, Campbellford map area, Ontario; GSC Paper 54-17.

Wilson, M. E., 1940a, Map 560A, Marmora; GSC.

Cartography by C. Merritt, 1972.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series, with additional information from staff surveys and from aerial photographs.

To accompany Water Resources Report 6

Ontario

MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch

WATER RESOURCES SURVEY

MOIRA RIVER DRAINAGE BASIN

MAP 3

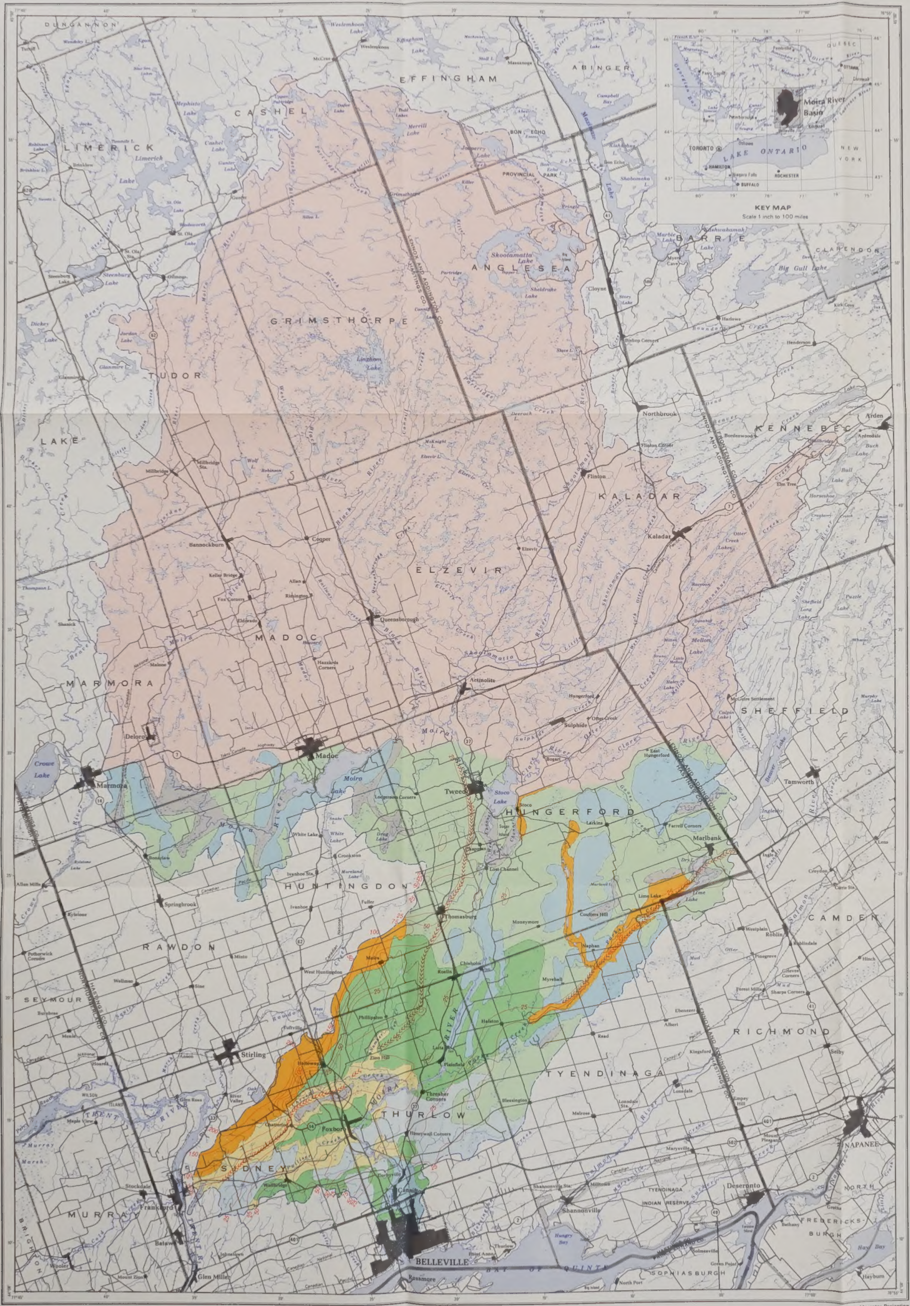
BEDROCK GEOLOGY AND TOPOGRAPHY

Scale 1:200,000
1 inch equals 3.16 miles

1 0 2 4 6 8 10
Miles

1 0 2 4 6 8 10 12 14
Kilometres

MAP 2762-3



Printed 1973

LEGEND

- **Peat and muck:** in swamps
- **Sand:** in lacustrine sand plain
- **Silt and clay:** in lacustrine clay plain
- **Sand and gravel:** in kame and outwash deposits; the top of the kame deposit has been reworked into Lake Iroquois beach gravels
- **Sand till:** in the Dummer end moraine and the associated ground moraine
- **Sand till:** in drumlinized till plain
- **Sand and gravel:** in esker
- Limestone
- Unmapped area (primarily rock outcrop)
- Geological boundary, approximate
- Line of equal overburden thickness (feet) *(Contour interval varies as shown on map)*

SOURCES OF INFORMATION

Generalized surficial geology compiled by U. Silbul, 1969, from cited references and limited field mapping. Surficial geology in the northern parts of the drainage basin have not been mapped.

References:

Chapman, L. J., and Putnam, D. F., 1966. The physiography of southern Ontario; University of Toronto Press.

Mirynech, E., 1962. Pleistocene geology of the Trenton-Campbellford map-area, Ontario; Ph.D. thesis, University of Toronto.

Ontario Department of Planning and Development, 1950. Soils map *in* Moira Valley conservation report.

Cartography by C. Merritt, 1973.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series, with additional information from staff surveys and from aerial photographs.

To accompany Water Resources Report 6

Ontario
MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch

WATER RESOURCES SURVEY

MOIRA RIVER DRAINAGE BASIN

MAP 4

GENERALIZED SURFICIAL GEOLOGY

Scale 1:200,000
1 inch equals 3.16 miles

1 0 2 4 6 8 10
Miles

1 0 2 4 6 8 10 12 14
Kilometres

MAP 2762-4

MOIRA RIVER — MAP 5
LOCATIONS OF WATER WELLS
DUNGANNON
LIMERICK
CASHEL
EFFINGHAM
ABINGER
BARRIE
CLARENDON
ANGLESEA
GRIMSTHORPE
TUDOR
LAKE
KENNEBEC
KALADAR
ELZEVIR
MADOC
MARMORA
SHEFFIELD
HUNGERFORD
HUNTINGDON
RAWDON
CAMDEN
RICHMOND
SEYMOUR
TYENDINAGA
THURLOW
SIDNEY
MURRAY
BELLEVILLE
SOPHIASBURG
KEY MAP
Scale 1 inch to 50 miles
LEGEND
Drilled well in overburden
Drilled well in bedrock
Abandoned drilled well in overburden
Abandoned drilled well in bedrock
Flowing drilled well in overburden
Flowing drilled well in bedrock
Drilled municipal well in bedrock
Well number
Note: When referring to well numbers on this map the appropriate county code prefix should be included. The county code is 29 for HASTINGS COUNTY and 37 for LENNOX AND ADDINGTON COUNTY.
This map shows the locations of wells as of July 1971 for which water well records have been filed with the Ontario Ministry of the Environment. In the areas of high well density, some wells have been omitted.
Cartography by C. Merritt, 1973.
To accompany Water Resources Report 6
Ontario
MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch
MOIRA RIVER DRAINAGE BASIN
MAP 5
LOCATIONS OF WATER WELLS
Scale 1:100,000
1 inch equals 1.58 miles
Miles
Kilometres
MAP 2752-5
Transverse Mercator Projection

LEGEND

- **Sand and gravel, surface;** deposits do not extend to the bedrock
- **Sand and gravel, surface;** deposits extend to the bedrock
- **Sand and gravel, buried;** deposits occur directly on the bedrock
- **Sand and gravel, surface and buried;** deposits are not interconnected
- **Sand and gravel, kame and outwash deposits;** complex distribution of aquifers, undifferentiated
- **Gravel pit**
- 10 Thickness of surface sand and gravel reported at a water-well location; 10+ indicates that more than the indicated thickness probably occurs at the site
- Thickness of buried sand and gravel reported at a water-well location; + indicates that more than the indicated thickness probably occurs at the site
- × No overburden aquifer reported at the location

ESTIMATED YIELDS FROM OVERBURDEN WELLS

- Less than 2 gallons per minute
- 2 to 10 gallons per minute
- Greater than 10 gallons per minute
- • No yield data available at this location

Note: Estimated yields are calculated from short-term test-pumping data and available drawdowns.

SOURCES OF INFORMATION

Interpretation by K. Goff, 1972.

Water well records on file with the Ministry as of July 1971.

Soil Survey of Hastings County, 1962, Report No. 27 of the Ontario Soil Survey, prepared jointly by the Research Branch, Canada Department of Agriculture and the Ontario Agricultural College.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series, with additional information from staff surveys and from aerial photographs.

Cartography by C. Merritt, 1973.

To accompany Water Resources Report 6

Ontario
MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch

WATER RESOURCES SURVEY

MOIRA RIVER DRAINAGE BASIN

MAP 6

OVERBURDEN AQUIFERS AND ESTIMATED YIELDS

Scale 1: 200,000

1 inch equals 3.16 miles

1 0 2 4 6 8 10
Miles

1 0 2 4 6 8 10 12 14
Kilometres

CA2ØNWR16
-74R06

LEGEND

- × Abandoned well (insufficient supply)
- Well with yield less than 2 gallons per minute
- Well with yield from 2 to 10 gallons per minute
- Well with yield greater than 10 gallons per minute
- Area where well yield is likely less than 2 gallons per minute
- Area where well yield is likely 2 to 10 gallons per minute
- Area where well yield is likely greater than 10 gallons per minute
- Area with insufficient data for interpretation

Note: Yields are estimates for individual wells based on theoretical calculations. Water well records on file with the Ministry as of July 1971.

SOURCES OF INFORMATION

Interpretation by K. Goff, 1972.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series, with additional information from staff surveys and from aerial photographs.

Cartography by C. Merritt, 1973.

To accompany Water Resources Report 6

Ontario

MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch

WATER RESOURCES SURVEY

MOIRA RIVER DRAINAGE BASIN

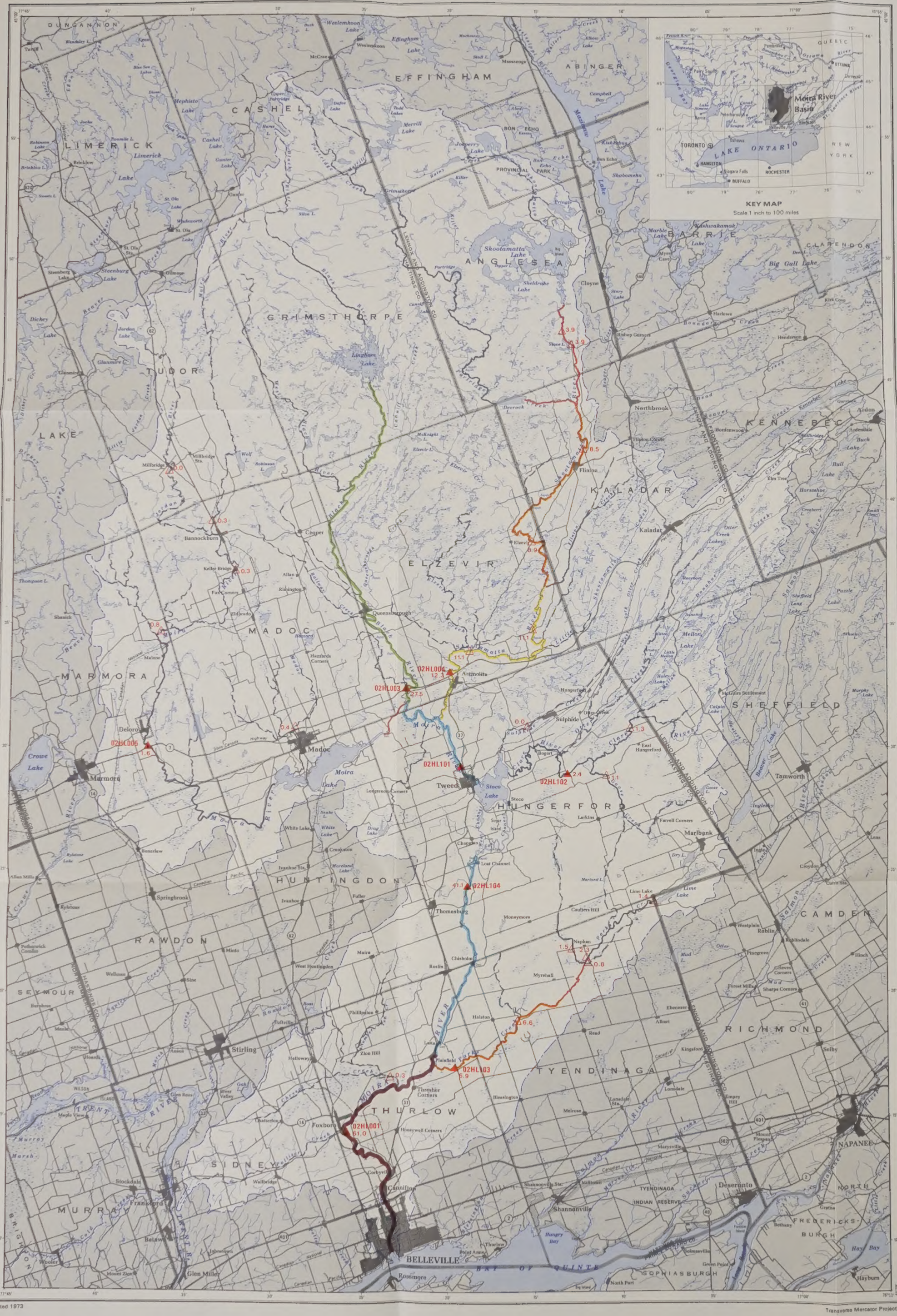
MAP 7

AVAILABILITY OF GROUND WATER FROM BEDROCK WELLS

Scale 1:200,000
1 inch equals 3.16 miles

Miles: 1 0 2 4 6 8 10
Kilometres: 1 0 2 4 6 8 10 12 14

MAP 2752-7



LEGEND

02HL001	Streamflow gauging station, recording gauge
△	Streamflow gauging station, periodic measurement
2.4	Daily streamflow equalled or exceeded 90% of the time

RANGE OF DAILY STREAMFLOW

- Less than 1 cubic foot per second
- 1 to 3 cubic feet per second
- 3 to 5 cubic feet per second
- 5 to 10 cubic feet per second
- 10 to 20 cubic feet per second
- 20 to 30 cubic feet per second
- 30 to 50 cubic feet per second
- Greater than 50 cubic feet per second

Note: Daily flows at recording gauge sites are based on the available period of record; values at periodic measuring sites are estimates based on correlations with adjacent recording stations.

SOURCES OF INFORMATION

Surface Water Data, Ontario; available from Environment Canada.

Interpretation by A. V. Choo-Ying, 1972.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series, with additional information from staff surveys and from aerial photographs.

Cartography by C. Merritt, 1973.

To accompany Water Resources Report 6

Ontario

MINISTRY OF THE ENVIRONMENT
Water Quantity Management Branch

WATER RESOURCES SURVEY

MOIRA RIVER DRAINAGE BASIN

MAP 8

DAILY STREAMFLOW EXCEEDED 90% OF THE TIME

Scale 1:200,000

1 inch equals 3.16 miles

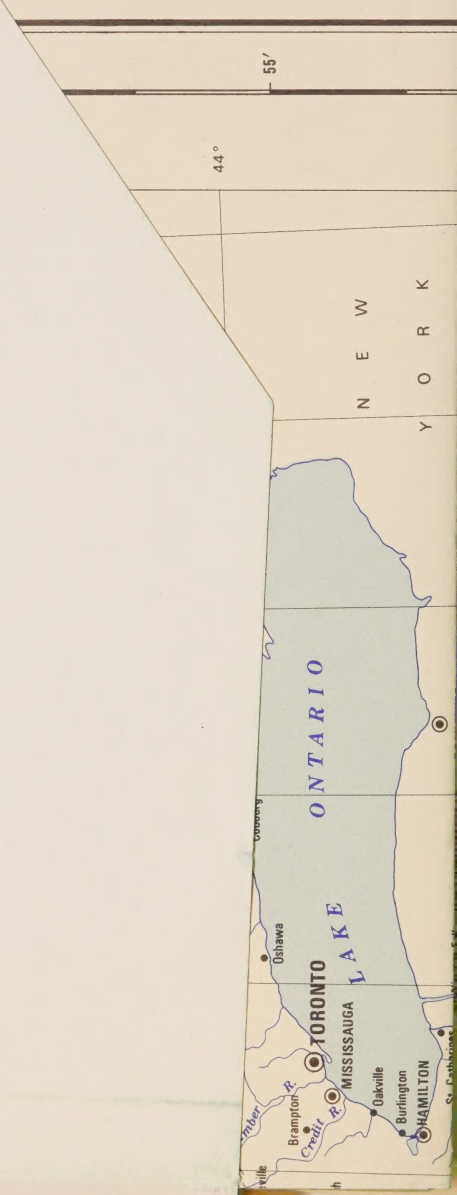
Miles: 1 0 2 4 6 8 10

Kilometres: 1 0 2 4 6 8 10 12 14

WATER RESOURCES REPORT 6

Maps in Pocket:

Map 1—Physiography and Sub-Basins
Map 2—Hydrometric Stations
Map 3—Bedrock Geology and Topography
Map 4—Generalized Surficial Geology
Map 5—Locations of Water Wells
Map 6—Overburden Aquifers and Estimated Yields
Map 7—Availability of Ground Water from Bedrock Wells
Map 8—Daily Streamflow Exceeded 90% of the Time



Ontario

Ministry of the Environment

Hon. George A. Kerr, *Minister*
Everett Biggs, *Deputy Minister*

Water Resources Report 6

Water Resources of the Moira River Drainage Basin

Ontario

WATER RESOURCES
REPORT 6

Water Resources of the Moira River Drainage Basin

By
U. Sibul, K. Goff and A. V. Choo-Ying

MINISTRY OF THE ENVIRONMENT

Water Quantity Management Branch

TORONTO ONTARIO

1974

Additional copies of this report and other reports published in the "Water Resources Report" series may be obtained from the Hydrology & Monitoring Section, Water Resources Branch, Ontario Ministry of the Environment, 135 St. Clair Avenue West, Toronto, Ontario, M4V 1P5.

PREFACE

The Moira River drainage basin is not a heavily populated area of the province, with only scattered settlement on the Canadian Shield portion of the watershed. However, the Moira Valley Conservation Authority has long recognized the value of water resources in the watershed and has expressed deep concern over its conservation and management. This report, the fourth in a series of drainage basin studies, presents an inventory of the resource on which such management and conservation in the Moira River basin can be based.

In contrast to the first three basins studied, the setting for water resources in the Moira River basin consists primarily of a bedrock environment, with an abundance of lakes and streams on the Canadian Shield. Surface water is a chief asset of the basin and an inventory of the quantity and quality of water in lakes and streams was a prime objective during field investigations in the area.

G. H. Mills, Director
Water Resources Branch

Toronto, April 1974

CONTENTS

List of Illustrations

Maps
(in case pocket)

List of Tables

ABSTRACT

The report presents an inventory of water resources in the Moira River basin in terms of surface- and ground-water occurrence, distribution, quantity and inorganic chemical quality. In addition, a brief outline of water use and associated problems is presented to assist in the formulation of water conservation and management policies in the watershed.

Field work was carried out in 1969 and 1970 and consisted primarily of limited geologic mapping, stream gauging, exploration for ground water through test drilling, and a comprehensive surface- and ground-water sampling program to determine the chemical quality of surface and ground waters. A network of eighteen observation wells was established to monitor ground-water levels in overburden, limestone, and in Precambrian rock environments. Four streamflow gauging stations were installed during the field year to supplement the previously existing four gauges in the basin.

There are three major hydrogeologic units in the basin: 1) overburden, 2) limestone, and 3) Precambrian rocks. Predictably high yielding aquifers have not been found in the watershed. Large yields can be obtained from fractured zones in the Precambrian rocks and from sands and gravels in the overburden but the most common source of water is from wells developed in limestone. Yields from limestone are usually less than 10 gpm.

Surface water in the numerous lakes and streams is a valuable resource and its conservation is a prime concern of the Moira River Conservation Authority. Replenishment of this resource is through precipitation which averaged 35.7 inches annually between 1966 and 1970 water years. Of this, the Moira River discharged an annual average of 10.0 inches of direct runoff and 4.0 inches of ground water out of the basin. Evapotranspiration losses claimed the largest proportion of the precipitation — an average of 23.5 inches annually over the five years, or approximately 66%.

The chemical quality of surface water is generally good in most parts of the basin but ground-water quality varies considerably with location and is highly mineralized in limestone wells in the southern sections of the basin. Most ground waters are of Ca-HCO_3 type, except in the south where ground waters of Ca-SO_4 and Na-Cl types are common.

Water management concerns in the basin consist mainly of shortages of surface water during low-flow periods in the summer, and of marginal ground-water supplies in certain parts of the Canadian Shield and in limestone in the southern third of the basin.

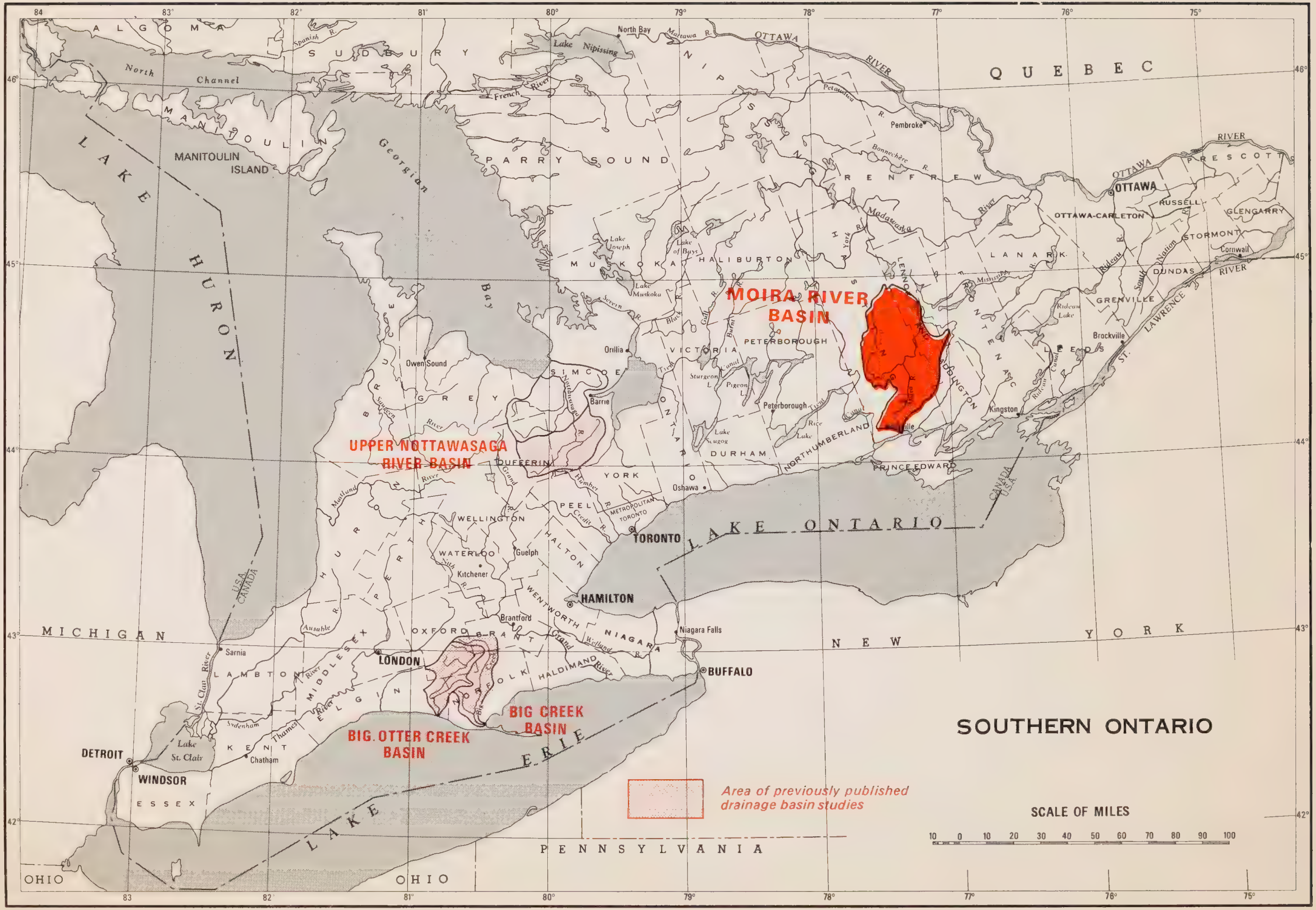


Figure 1. Location and extent of Moira River basin

INTRODUCTION

Purpose and Scope

The water resources survey in the Moira River basin was undertaken in response to concern expressed by the Moira River Conservation Authority regarding the future availability of surface and ground waters, and the long-term effect(s) of on-going water-resources development in the basin. The survey was designed to gain an understanding of the occurrence, distribution, quantity, quality, and use of surface and ground waters, and in the course of this work to establish an effective hydrometric network for gathering surface- and ground-water data for future water management and planning in the basin.

The survey began in 1969 and continued for two years, during which time field work consisted of stream gauging, the installation of observation wells, stream gauges, and an evaporation station, geologic mapping, and surface- and ground-water sampling for chemical analyses. The report deals mainly with general hydrologic conditions in the basin rather than with specific situations on a local scale.

Location of the Area

The Moira River watershed extends 55 miles northward from Lake Ontario to cover an area of 1060 square miles in the counties of Hastings, and Lennox and Addington (Figure 1). Major urban centres in the basin are the City of Belleville, which is located at the mouth of the Moira River, and the villages of Tweed and Madoc. The basin, for the most part, is in the Highlands of Hastings and Land O'Lakes tourist regions.

It should be noted that the northern portion of the basin extends onto the Canadian Shield where the hydrologic environment is considerably different from that in approximately the southern third of the basin.

Previous Investigations

The *Moira Valley Conservation Report* (Ontario Department of Planning and Development, 1950) deals comprehensively with land use, forestry, water, wildlife, and recreation in the basin, and is a major reference for the natural resource inventory in the watershed. The water section deals mainly with surface-water hydrology, with considerable attention given to analysis of flood flows. This report was summarized in two subsequent reports: *Moira Valley Conservation Report—1950—Summary and Recommendations,* and *Moira Valley Conservation Report 1955,* both published by the Ontario Department of Planning and Development.

A series of nine studies dealing with resources development in the Tweed Forest District were published by the Ontario Agricultural College at Guelph in 1963 and 1964. Studies 1, 5, 6, 8, and 9 were useful in preparing this report, and all nine reports are listed by their respective authors in the bibliography. The *Lake Ontario Region Economic Survey* (Ontario Department of Economics and Development, 1968), includes a demographic study in the area, industrial and manufacturing statistics, and a brief description of water resources in the region.

Palaeozoic geology in the basin has been described by Liberty (1960, 1963) and Winder (1955). Large regional geologic surveys, which include that part of the watershed underlain by Precambrian rocks, have been published by Harding (1942), Hewitt (1964, 1966, 1968), Lumbers (1969) and Wilson (1940).

Reports on surficial geology and physiography have been prepared by Chapman and Putnam (1966) and by Mirynech (1962, 1967) who mapped the surficial deposits in the Trenton-Campbellford topographic map areas.

Water quality reports published by the Ontario Water Resources Commission include *Water Pollution Survey of the Village of Deloro, County of Hastings* (OWRC, 1971), *The Role of Nutrients and Their Budgets in the Bay of Quinte, Lake Ontario* (Johnson and Owen, 1970) and *Biological Survey of the Moira River* (Owen and Galloway, 1969). Gasoline pollution of ground water has been investigated in the Madoc and Cannifton areas and at Millbridge (Ministry of the Environment, internal reports). In addition, a number of unpublished ground-water surveys in the basin are on file with the Ministry. The arsenic problem originating at the Deloro Stellite mine site is documented in a report by J. F. MacLaren Limited (1971).

Acknowledgements

Co-operation was extended by members of the Moira River Conservation Authority at Cannifton and the Ministry of Natural Resources (formerly the Ontario Department of Lands and Forests) at Tweed. Thanks are extended to the Canada Atmospheric Environment Service (formerly the Meteorologic Branch of the Canada Department of Transport) for installing a Class A pan evaporation station near Stoco Lake, and to Mr. J. Marshall who operated the station.

Mr. Dhan Sharma was responsible for gathering much of the field data throughout the period of study and assisted in preparing the text of the report. Field and office duties during the summer of 1969 were ably carried out by Messrs. R. Hillary, R. Devereux, and J. Z. Johnston. Mr. D. Pysklywec assisted in editing parts of the text.

Mr. T. J. Yakutchik offered helpful suggestions during the course of the field survey and Mr. R. C. Hore provided constructive comments during editing of the draft report.

GEOGRAPHY

Physiography

The basin is divisible into two major physiographic regions which in general conform to the two major geologic environments in the watershed: one is characterized by Precambrian bedrock topography of the Canadian Shield and the other by topography due to mainly thin overburden glacial deposits on Palaeozoic limestones (Map 1). Precambrian geology is shown on Map 3 and the generalized surficial overburden geology on Map 4. Elevations in the basin vary between 250 in the south and 1500 feet in the extreme north but most of the land is in the range of 500-1000 feet above sea level. Local relief rarely exceeds 200 feet.

The northern two-thirds of the basin is in a major physiographic region where overburden on the Precambrian bedrock is thin or absent and, for the most part, the land terrain reflects the rock-and-knob configuration of the bedrock. Overburden landforms are limited to occasional kame mounds, esker ridges, and sand plains formed by sediment accumulation in bedrock depressions. Swamp and bog deposits fill numerous bedrock lows and surround many lakes. The parallel drainage pattern in the vicinity of Otter and Donahue creeks (in the Clare River sub-basin) is a distinctive feature not duplicated elsewhere in the basin. This pattern is the result of the differential erosion of metamorphic rocks in a geologic setting known as the Clare River Syncline.

The southern third of the basin lies within the second major physiographic region and is characterized by abundant overburden landforms on Palaeozoic limestones. Surface relief is provided mainly by moraines, eskers, and drumlins, but in many areas the mantle of overburden is thin and surface topography reflects the gently sloping surface of the underlying limestone bedrock. A discontinuous limestones cuesta, usually less than 30 feet high, defines the contact between Precambrian plutonic rocks and Palaeozoic limestones in areas east, south and west of Stoco Lake (Map 3). Highest relief in the region occurs in the southwestern part of the basin where the sand and gravel deposits between Moira and Frankford (Map 4) reach an elevation of over 700 feet. This is approximately 200-300 feet above the surrounding till and sand plain to the southeast.

Drainage

The Moira River and its major tributaries, Skootamatta, Black, and Clare rivers, and Parks Creek, drain approximately 1060 square miles. Average stream gradients vary from a low of 6 feet per mile on the Clare River, to as much as 34 feet per mile for Chrysal Creek (Figure 10), which is a small tributary of the Moira River that has its headwaters in the kame moraine northwest of Chatterton.

The drainage pattern in the Precambrian area is mainly dendritic, except in the Clare River sub-basin where northeast trending ridges and valleys give rise to parallel stream patterns. In the south, sub-parallel drainage patterns are associated with minor north-northeast surficial lineations related to glaciation. Headwater erosion has not yet reached many upland swamps in the southern parts of the basin and in the north resistant rock formations retard drainage development beyond youthful stages.

The largest lakes in the basin are Skootamatta, Lingham, Moira and Stoco lakes.

Table 1. Selected Meteorological Data from Eight Sections in and around the Moira River Basin

Station	Period of Record (approximate) From	To	Mean Annual Precipitation (inches)	Mean Annual Snowfall (inches)	Maximum Precipitation in 24 Hours (inches)	Mean Daily Temperature (°F)	Maximum Temperature on Record (°F)	Minimum Temperature on Record (°F)
Bancroft	1882	x	32.56	70.9	3.27	40.2	100	–47
Belleville*	1866	x	33.86	71.0	4.18	45.2	104	–39
Belleville OWRC (formerly Belleville Par. Lab.)	1929	x	33.57	67.3	4.08	45.8	105	–35
Queensboro*	1914	1946	32.85	69.1	2.95	42.3	102	–46
Stirling	1940	1968	30.67	64.2	3.36	43.8	98	–32
Trenton Airport	1935	x	33.42	66.9	3.82	45.3	102	–26
Trenton Ontario Hydro	1915	x	32.77	63.9	3.55	—	—	—
Tweed*	1925	x	34.47	76.3	3.65	43.9	105	–40

*Locations shown on Map 2; other stations are outside the map area

x Operative in 1970

SOURCES OF INFORMATION
Canada Department of the Environment (?)
Canada Department of Transport (1968, 1970)

Climate

A total of nine meteorologic stations in and around the basin are used to characterize climate in various areas of the watershed (Map 2). Bancroft is the most northerly station, being about 20 miles north of the basin, and Belleville is in the extreme south at the mouth of the Moira River. Data on precipitation and temperature at eight of the stations are listed in Table 1. Cloyne station is not included in this table because it had only three years of record to the end of 1970, a period too short to establish mean values comparable to the long-term means indicated in the table.

Temperature and precipitation are variable in the region. The lowest annual mean daily temperature of 40.2°F is found at Bancroft and generally the means increase at stations towards the south. Highest mean of 45.8°F is for the OWRC station at Belleville.

The highest mean annual precipitation of 34.47 inches occurs near the centre of the basin at Tweed with mean precipitation in the north, as indicated at Bancroft, being 32.56 inches annually. Annual precipitation in the south at Belleville averages 33.86 inches. The lowest mean annual precipitation in the area is shown to be at Stirling—30.67 inches. Mean annual snowfalls vary from 63.9 inches at Trenton, which is about 10 miles west of Belleville, to a high of 76.3 inches at Tweed.

The Ontario Department of Agriculture and Food (1966) indicates the southern part of the basin to be in the South Slopes climatic region, the central part is in the Simcoe and Kawartha Lakes region, and the northern portion lies in the Haliburton Slopes climatic region. The mean frost-free period in these three regions varies between 110 and 145 days, and the mean annual growing season (mean daily temperature above 43°F) ranges from 190 to 200 days.

Population, Land Use and Economy

The population of the basin in 1974, including the City of Belleville, was estimated to be 54,000. The major population centres are Belleville (35,125), Tweed (1753), Madoc (1322), and Deloro (231) (Ontario Ministry of Treasury, Economics and Intergovernmental Affairs, 1975).

Industry and agriculture form the economic base in the southern third of the basin, while tourism, recreation, and logging are major activities in the north where 80 per cent of the region is woodland.

The area south of Thomasburg and the area bounded by Queensborough, Madoc, Malone and Kellers Bridge are the only large areas in the basin where the soils are suitable for general agricultural use. Approximately 40 per cent of this land area is cultivated, and dairying, beef production, and mixed farming account for more than 90 per cent of the agricultural operations. The current trend is toward fewer but larger farms.

Geologic Setting

Precambrian metamorphic and plutonic (igneous) rocks underlie the whole of the basin (Map 3). They outcrop in the north to form the Canadian Shield, and are in turn overlain in the south by as much as 250 feet of Palaeozoic limestone. All of the basin has been glaciated, as evidenced by glacial deposits in most parts of the basin. These deposits are usually thin and discontinuous on the Shield but become thicker and more continuous towards the south.

Precambrian bedrock in the northern two-thirds of the basin consists of metasedimentary, metavolcanic, and plutonic rocks. The bedrock surface is largely exposed and the rock-and-knob terrain is characterized by generally low relief. The Clare River Syncline is a pronounced bedrock feature in the east-central portion of the basin where differential erosion of metamorphic rocks has produced a parallel drainage system. Bedrock structures in areas of igneous rocks usually consist of granitic bosses, of which Mount Moriah is a good example.

Limestones in the southern third of the basin consist of the Trenton and Black River groups of Ordovician age (Map 3). The limestones are finely crystalline to lithographic with argillaceous facies, and individual limestone beds are usually thin, dipping southward at about 20 feet per mile (Liberty, 1960). At many locations thin basal deposits of red and green shale, sandstone, and arkose (Shadow Lake Formation) separate the limestone from older Precambrian rocks. The Palaeozoic formations thicken from their erosional edge south of Tweed to a maximum recorded thickness in the basin of 250 feet near Belleville.

The limestone bedrock surface slopes generally southward and controls to a large extent the configuration of the present land surface topography. This control is especially noticeable in areas of till and limestone plains in the southeastern portions of the watershed, and throughout almost the whole length of the Moira River valley south of Stoco Lake. In addition, the sand and gravel upland area in the southwestern part of the basin is underlain by a bedrock high which may have been a nucleus for the formation of the kame moraine.

Overburden deposits are thin or absent over much of the Canadian Shield, and where present, consist mainly of sands and gravels of fluvial and ice-contact origin. The extent, continuity and thickness of these deposits is not known. Overburden on the Palaeozoic limestones consists primarily of glacial till, glaciofluvial sand and gravel, and lacustrine sand, silt, and clay (Map 4). Overburden in the south is generally less than 50 feet thick (as indicated on Map 4) but it does reach thicknesses greater than 200 feet in the kame moraine along the southwestern boundary of the watershed. The moraine is approximately 15 miles long and attains a relief of 200 to 300 feet above the surrounding land surface. Most of the moraine consists of sand and gravel, although till occurs at the surface in some elevated parts of the moraine.

Two esker ridges are prominent in the basin. One is the sand and gravel ridge that trends southwest from Marlbank to just south of Myrehall. Intermittent traces of this ridge crop up near Latta, and just northeast of Foxboro the sand ridge again becomes a prominent feature on the plain. This esker has been traced by Mirynech out of the basin as far as Biddy Lake near Colborne (Chapman and Putnam, 1966), a total length of approximately 65 miles. The other esker ridge is locally known as the Tweed Esker and is thought to be a northern tributary of the esker through Marlbank. The Tweed Esker is similarily a narrow ridge of sand and gravel prominently displayed on the till plain between Tweed and Zion Hill. It is approximately 18 miles long.

Most of the landscape south of Tweed is covered by sand till. The northern sand till sheet is part of the Dummer Moraine discussed by Chapman and Putman (1966). In most areas within the Dummer Moraine the sand till is thin and the ground surface is littered with large limestone and Precambrian boulders. The moraine itself is not well defined in many areas as broad, gently undulating till plains within the moraine coalesce with limestone plains east and northeast of Moneymore, and with the drumlinized till plain to the south. The drumlinized till plain is prominent in the east-west band of till cover between Roslin and Thresher Corners and represents the eastern extent of a larger drumlinized plain located west of the basin.

Lacustrine deposits of sand, silt, and clay form low plains drained by Chrysal and Palliser creeks, and an extensive but thin cover of clay is found in the plain north and northeast of Honeywell Corners.

GROUND WATER

Introduction

The distribution of aquifers, together with their hydrologic properties and yields of water to wells, is presented, along with an evaluation of the potential ground-water resources in the basin. All hydrogeologic interpretations have been based on information obtained from water-well records filed with the Ministry, and on information gathered through field investigations carried out during 1969 and 1970. The locations of water wells are shown on Map 5. Due to their high density in some areas, especially in towns and villages, all existing wells in the basin are not shown; however, where well density is low, all wells on file have been plotted on the map.

The Moira River basin is divisible into three major hydrogeologic units: (1) overburden, (2) Palaeozoic limestones, and (3) Precambrian plutonic and metamorphic rocks. The Precambrian unit underlies the entire basin and outcrops in most of the nothern areas of the watershed. In the southern third of the basin it underlies Palaeozoic limestones, which in turn are overlain by usually thin overburden deposits.

The overburden unit is distinct from the two bedrock units insofar as it is composed of unconsolidated deposits which possess intergranular porosities in the range of 10 to 40 per cent. By contrast, intergranular porosity in the Palaeozoic and Precambrian bedrock is practically non-existent and ground water occurs in cracks, fractures, and joints in the rock. Porosity in the rock is generally in the range of 1 to 3 per cent, but it may be slightly higher in the limestones because mineral dissolution by ground water may enlarge the volume of cracks, joints and fractures.

Occurrence In Overburden

The distribution of overburden in the Precambrian portion of the basin was not investigated in detail. Significant deposits of sand and gravel have been observed in the field at a number of locations in the north , but detailed information is not available regarding their extent, continuity, thicknesses and water-bearing capacities.

The overburden is a significant source of ground-water supplies only in the southwestern part of the basin. Elsewhere in the south the overburden is relatively thin and consists mainly of glacial till, which is normally a poor source of ground water. Map 6 outlines the overburden aquifers and indicates yields which can probably be obtained from existing wells. There are two main overburden aquifers in the southwestern part of the basin: (1) thick sand and gravel deposits within the kame moraine along the southwestern edge of the basin, and (2) the sand deposits that adjoin this moraine and extend eastward along Chrysal and Palliser creeks, and along Parks Creek. Because sands and gravels occur at the surface over much of the moraine, rainwater infiltrates into the ground easily and stream development in the area is poor. Where till is present on the surface, shallow perched water-table often outcrops to produce lakes and swamps on an otherwise well-drained terrain.

Yields from most wells completed in sands and gravels in the moraine exceed 10 gpm (Map 6) and tend to be larger than yields from rock or from overburden in other parts of the

basin. However, in spite of these above average yields, the specific capacity of three-quarters of the wells is only 1 gpm per foot or less, indicating that most of the sands and gravels are not extensive and/or are poorly sorted. Several wells on the moraine have significantly larger specific capacities, suggesting that large yields are possible in some locations. Water levels in most wells on the moraine are approximately 50 feet deep.

The moraine is an area of ground-water recharge and from it ground water moves generally eastward. However, discharge does occur on the flanks of the moraine as indicated by local swampy areas and by sustained flows during the summer low-flow periods in Chrysal Creek and its tributaries.

Rural domestic wells have been constructed in the sands and gravels, and at most locations these wells are not taxing the full potential of the aquifer. However, additional development in the area should ensure that new wells are sufficiently spaced to avoid interference with water levels in nearby existing wells.

The only other known significant overburden aquifer in the basin consists of sand deposits adjoining the kame moraine and extending eastward along Palliser and Chrysal creeks as far as the Moira River, and along Parks Creek (Map 6). The deposit is buried in places by clay and till, and by swamp deposits along the Moira River. Although thicknesses in excess of 60 feet have been encountered in some wells, at most locations the deposit is less than 20 feet thick. Thin layers of gravel have been reported in some of the wells, but these gravels are not extensive and indicate minor fluvial deposition in an otherwise lacustrine environment.

Yields from most wells in the sands are approximately 10 gpm, although yields of 40 to 50 gpm should be possible from the thickest sections of the aquifer. In places these sands are reported to directly overlie the limestone and a good hydraulic connection exists between the sand deposit and bedrock.

As in the case of aquifers in the kame moraine, the sand aquifer is not developed to its full potential. Most wells in the sand produce relatively small quantities of water to satisfy rural domestic needs and high-capacity wells are not common. The density of wells in the sand is low and can be increased considerably without overdeveloping the aquifer in any specific area. However, adjacent wells should be spaced far enough apart to prevent interference.

Occurrence In Limestone

Limestone is the most common source of ground water in the southern third of the basin. Water is obtained from a variety of depths in the rock but most wells obtain suitable supplies from the upper 35 to 40 feet of the limestone.

Yields from limestone wells are variable but most are less than 2 gpm (Map 7), which is only marginally adequate for domestic uses. Areas in the basin where well yields are greater than 2 gpm usually correspond with bedrock depressions where the overburden is thick and consists of water-bearing sands and/or gravels. Dry wells in the limestone occur randomly in the basin; however, the greatest concentration occurs near Lake Ontario (maps 5 and 7).

The limestone aquifer is generally not fully developed, except in villages and rural areas where many wells are located close to each other and obtain water from the same zone. Additional wells can be developed in areas where the present well density is low, but yields to these wells should not be expected to exceed 10 gpm. Also, drilling beyond 30 to 40 feet into the limestone will generally not increase yields.

Several wells, especially in the area between Madoc and Eldorado, reportedly obtain water supplies from 'sandstone'. This rock may be part of the Potsdam Formation found east of the basin, or it may be the discontinuous basal arkose deposit of the Shadow Lake Formation, which immediately overlies the Precambrian bedrock at many locations in the basin. Yields from this 'sandstone' unit are generally better than from adjacent wells constructed in limestone or Precambrian rocks. However, only a few wells report 'sandstone' and the formation is considered to be of local significance only.

Occurrence In Precambrian Rocks

Approximately 85 per cent of the 400 wells drilled in this hydrogeologic region obtain suitable supplies within 50 feet of the ground surface, although deeper wells do occur. Because ground-water yield from rock is a function of the number and size of rechargeable, water-filled fractures and joints encountered by a well, and as these openings may begin and end abruptly, follow complex trends and possess strong directional orientation, well yields can be expected to be variable. Yields in excess of 200 gpm have been reported from municipal wells at Deloro, Madoc and Tweed, while 40 per cent of the domestic wells in the Precambrian rocks have yields less than 2 gpm. Five per cent have reportedly failed to obtain sufficient water for domestic uses. The municipal wells are considerably deeper than most other wells constructed in the Precambrian bedrock. These wells, the deepest of which is the 435-foot well at Tweed, are located in areas of relatively complex geology and it is likely that folding and faulting associated with metamorphism have resulted in rechargeable fractures and joints at depth.

Observation-Well Network

The observation-well network in the basin provides information on the occurrence of aquifers and ground-water level fluctuations in overburden (mainly glacial drift), limestone, and Precambrian environments. The locations of observation wells are shown on Map 2 and the history of each well is summarized in Table 16 in Appendix A.

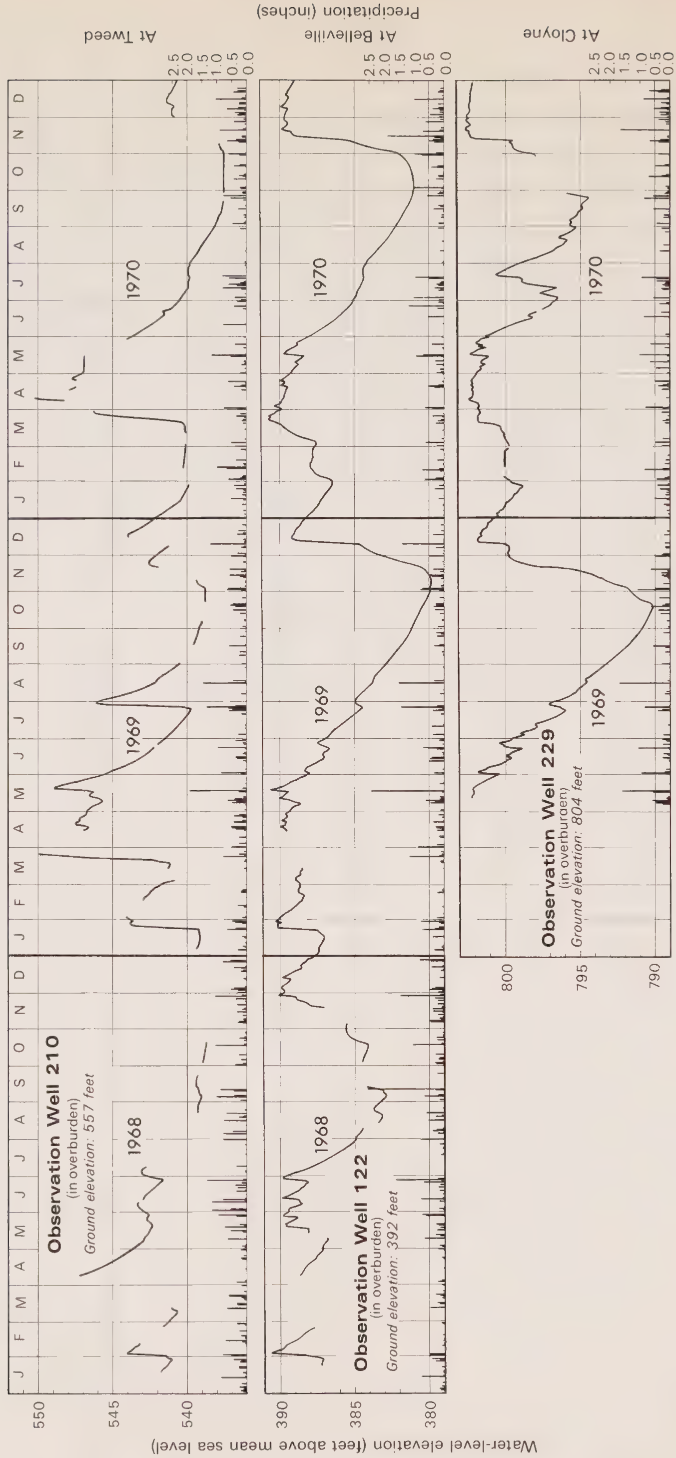
With the exception of three sites, at which the wells were drilled specifically for this study, the network consists of abandoned domestic wells. Efforts were made to locate an equal number of wells in overburden, limestone and Precambrian environments to obtain water-level information in the three major hydrogeologic units. However, only a limited number of abandoned wells were found and the choice as to well depth, location and aquifers sampled was restricted.

Six wells are constructed in overburden; three are equipped with automatic water-level recorders, and in the other three the water levels are measured manually once a month. Eleven observation wells monitor piezometric levels in limestone formations; five are equipped with automatic recorders, and the remaining six are measured manually. One observation well is located in an area of metasedimentary rock on the Shield and indicates water-level fluctuations in a Precambrian environment.

Water-Level Fluctuations

Ground-water level fluctuations can vary significantly in different geologic environments and consequently a study of water-level fluctuations in the three major geologic settings in the Moira River basin was carried out. The purpose of this study was to obtain data that may subsequently be used to resolve or prevent future ground-water problems, and to assist in planning of ground-water utilization in the watershed.

Water-level hydrographs are the primary and the most basic means of indicating changes in water levels in wells, and seven of these graphs are shown in Figure 2. Three graphs indicate water-level changes in overburden (wells 210, 122, and 229), three graphs portray changes in limestone (wells 123, 209, and 256), and one graph shows short-term water-level fluctuations in Precambrian rock (well 230). The hydrographs indicate the total range of annual fluctuations between 1968-1970, where data is available, and are one important means of determining periods in the year when ground water receives recharge to storage, and when this storage is being depleted.


Observation Well 210
(in overburden)
Ground elevation: 557 feet
Observation Well 122
(in overburden)
Ground elevation: 392 feet
Observation Well 229
(in overburden)
Ground elevation: 804 feet
1968
1969
1970
J F M A M J J A S O N D
Water-level elevation (feet above mean sea level)
550
545
540
390
385
380
800
795
790
Precipitation (inches)
2.5
2.0
1.5
1.0
0.5
0.0
At Tweed
At Belleville
At Cloyne

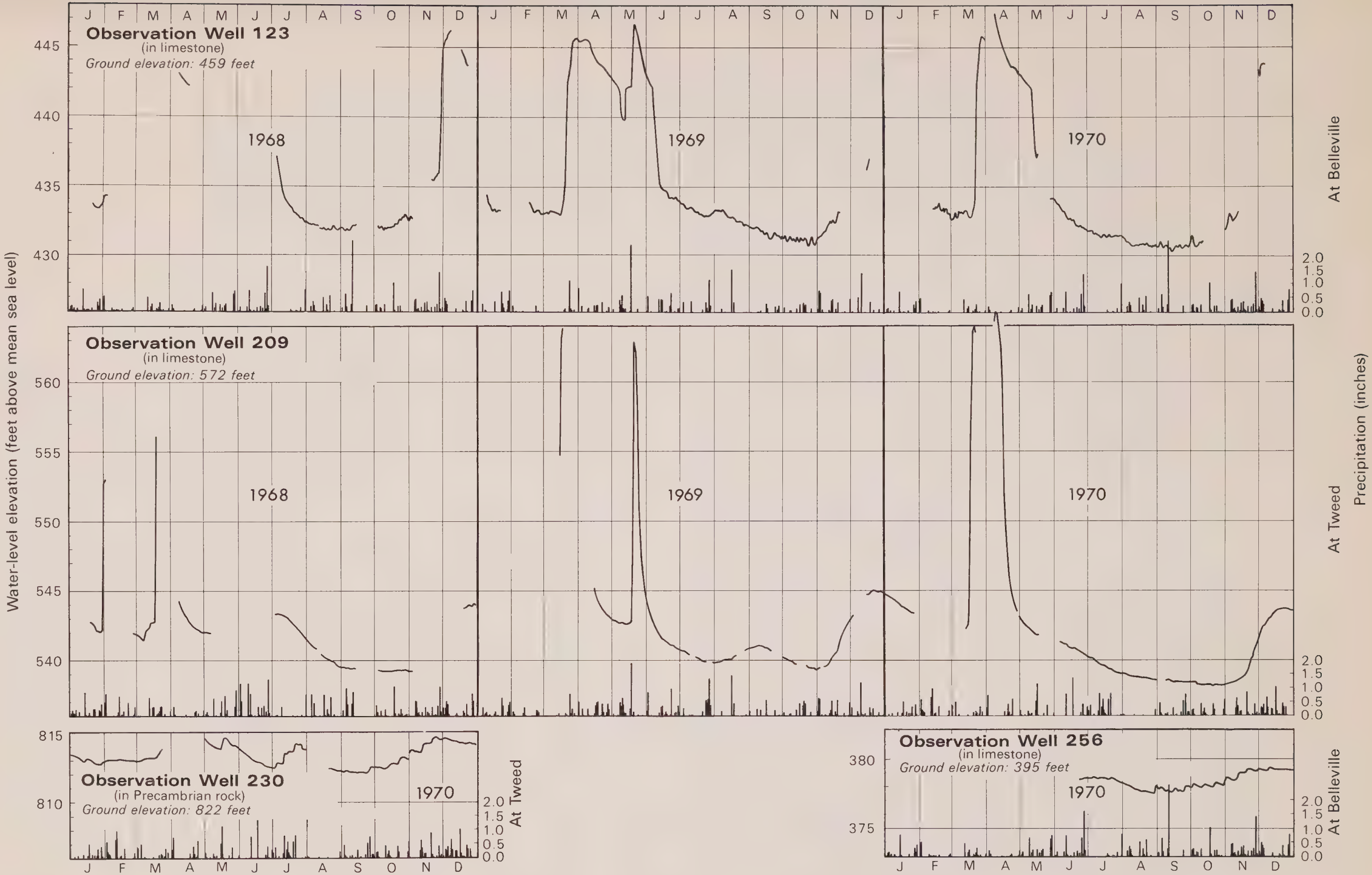


Figure 2. Water-level hydrographs for observation wells completed in overburden, limestone, and Precambrian rock.

The recession curves shown in Figure 3 were derived from hydrographs in Figure 2, and represent the composite recession of water levels in each well. The recession curves can be readily used to predict levels in wells, knowing the depth of water in the well to begin with.

Ground water is wholly dependent on precipitation for recharge. During periods of low precipitation, ground-water levels decline rapidly, while during 'wet' years, water levels in wells are maintained at high levels. The correlation of water-level responses with precipitation events was consequently studied to define the interdependence of these two factors, and to determine if there is any correlation between rainfall amounts and water-level responses during the summer months when ground-water levels are usually declining.

In Overburden

Observation wells 122, 210 and 229 are equipped with continuous water-level recorders, and are used as 'index' wells for studying water-level fluctuations in shallow overburden deposits. Each well is constructed in an area of surficial sand till, and the water level in each is considered to approximate the water-table. Hydrographs for the three wells indicate similar seasonal trends, with extended periods of high levels during the spring months of March, April and May, and highs usually occurring again in December (Figure 2). Peaks during the summer occur as a result of heavy rainfall, but do not represent predictable occurrences and therefore are not used to characterize ground-water level hydrographs in the watershed. The recession curves for all three wells are very similar in shape (Figure 3), indicating similar hydrogeologic conditions at the three sites. The same permeability at all sites is probably the most important single factor that is responsible for the similarity in the shape of the curves.

Fluctuations at Well Site 210

During the summer of 1969, a recording rain gauge was installed near this well and was operated from May until October to investigate infiltration rates and water-table responses to rainfall. For the six month period of study, the following conclusions were reached:

(1) the only time it was possible to discern a water-level response to rainfall was when precipitation exceeded approximately one inch; however, not all rainfall events over one inch affected the water level; only twice during the summer did the water level in the well rise as the result of rain;

(2) following rainfall events on May 17 and August 16, time lags between the start of rain and water-level reaction were estimated, and percolation rates in the order of 1.5 feet per hour at 11-foot water-table depth, and 2.0 feet per hour at 16-foot depth respectively, were obtained. However, these rates apply only for the soil moisture conditions existing at the time and do not reflect 'absolute' percolation rates. The antecedent soil moisture conditions prior to these rainfall events were not known.

Results of the correlation of water levels with precipitation at this site indicate that only a small proportion of summer precipitation reaches the water-table to increase ground-water storage in the area. What little does percolate all the way down is usually not sufficient to change the downward trend of the water level during the summer months.

Fluctuations at Well Sites 122 and 229

Observation wells 122 and 229 are both constructed in till, and since the water-level hydrographs for the two wells are very similar (Figure 2), water levels in the wells are considered to reflect similar hydrogeologic environments. Annual highs in December and the spring months are prominent in both hydrographs.

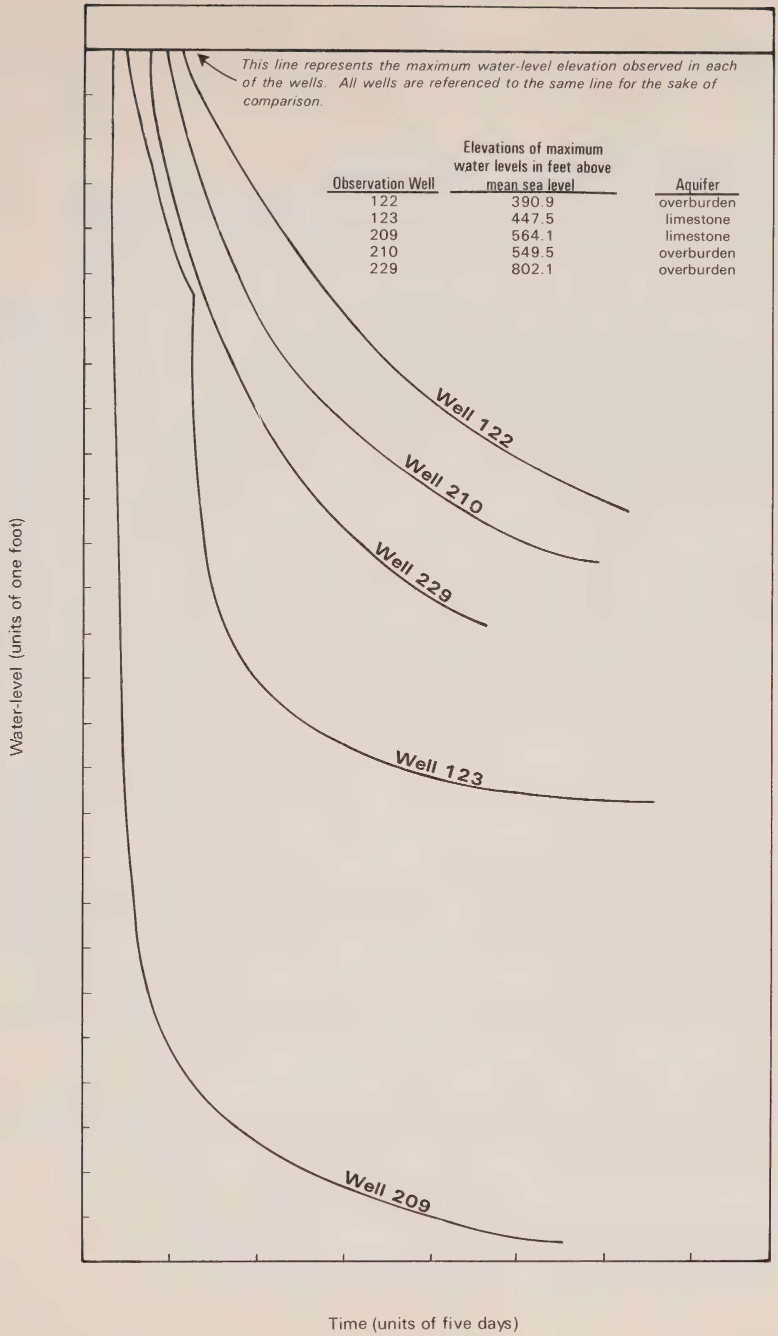
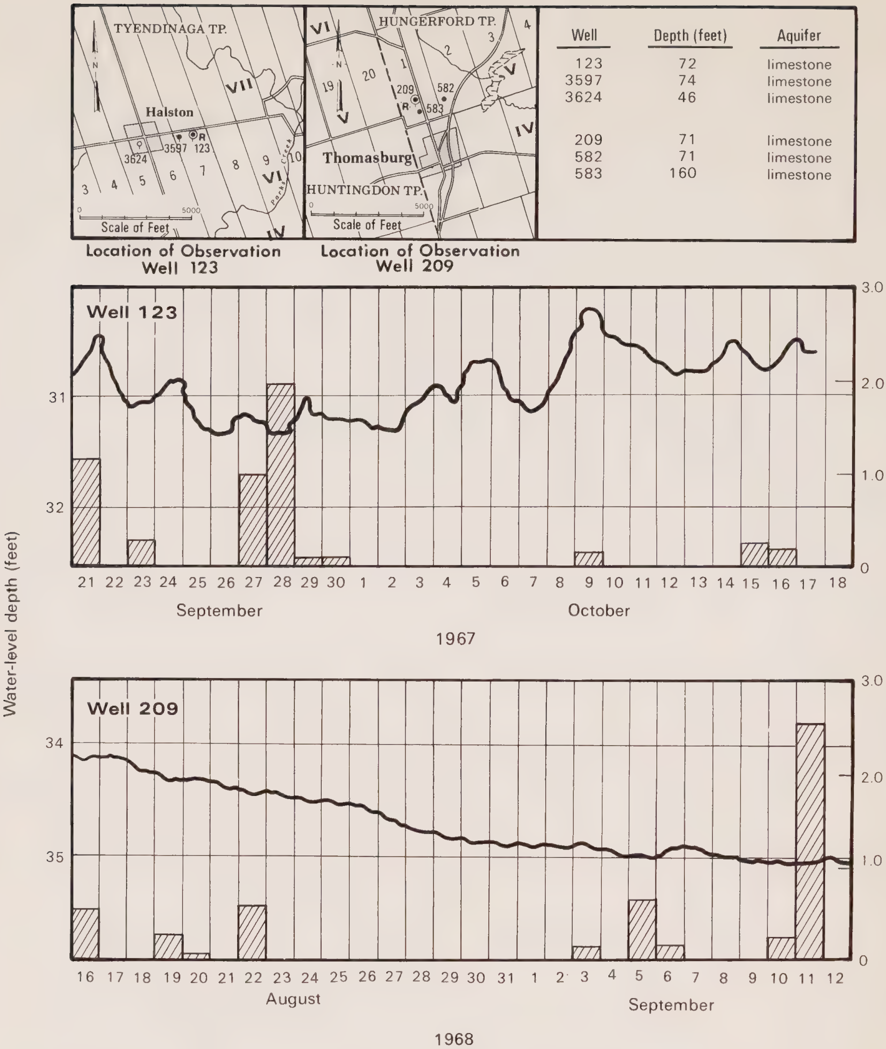


Figure 3. Water-level recession curves for five observation wells in the Moira River basin (1968-1970 data).



Well	Depth (feet)	Aquifer
123	72	limestone
3597	74	limestone
3624	46	limestone
209	71	limestone
582	71	limestone
583	160	limestone

Figure 4. Water-level hydrographs for observation wells 123 and 209, both indicating interference caused by pumping from nearby domestic wells.

At site 122, precipitation events cause noticeable increases in water level during spring and early summer when soil moisture is probably near field capacity, but the magnitude of response diminishes during the summer as soil moisture deficiencies increase. During dry periods in August and September of 1969 and 1970, the water level in well 122 showed little response to rainfall.

The water level in well 229 reacts generally in the same way as in well 122, but in many instances water-level rises in well 229 are larger for approximately the same precipitation during the summer. Examples of such larger water-level increases are shown by precipitation on June 2, June 23 and July 27, 1969, and during rainfall in June and July of 1970 (Figure 2).

In Limestone

Observation wells 123, 209 and 256 are equipped with continuous water-level recorders and their hydrographs indicate fluctuations of the piezometric surface in limestone aquifers.

The following points are inferred from water-level data collected at these wells (Figure 2):

(1) the water-level hydrographs at wells 123 and 209 indicate interference by adjacent pumping wells (Figure 4) but seasonal water-level fluctuation trends are not altered significantly;

(2) the hydrographs for wells 123 and 209 show similar seasonal trends. The main difference is in the magnitude of respective peaks: the spring peaks in well 209 are usually higher and of shorter duration, and the daily water-level fluctuations during summer recession are of smaller magnitude than those in well 123;

(3) the water level in well 256 represents an average hydrostatic pressure over the total thickness of uncased limestone penetrated at the site. Consequently, the water-level fluctuation cannot be attributed to hydrostatic pressure changes from a discreet water-bearing zone in the uncased portion of the drill hole. The hydrograph of this well is presented for general information only as it does not lend itself to detailed analyses at this time because of the short period of record available.

The differences in the shape of the hydrographs in limestone wells 123 and 209, and those in the three overburden wells are obvious. The much higher peaks in limestone are a characteristic feature and suggest much smaller storage capacities than those existing in overburden. Consequently, the amplitudes of annual fluctuations in limestone are nearly twice that in overburden, and the depth of pump intakes would have to be increased proportionately in limestone wells to avoid wells periodically going 'dry'.

Fluctuations at Well Sites 123 and 209

These wells are 72 and 71 feet deep respectively, and interference is suspected in both wells. Well 123 is near Halston and is very close to pumping well 3597 which obtains its water from the same formation as well 123. Well 209 is near Thomasburg and is close to several domestic wells in current use (Figure 4).

The general pattern of interference in well 209 indicates the beginning of water-level decline at about 8 a.m. and continuing for approximately 8 hours, after which time the water level is stable for about 16 hours. This cycle is generally repeated throughout the summer except during or after rainfall events when the level may recover slightly. In some instances the water level also recovers after pumping, but more often it continues its recession without daily recovery.

No diurnal cycle is apparent in well 123.

Two features are noteworthy on hydrographs from both wells. First, very large daily water-level fluctuations occur during spring. For example, on March 18, 1968, the water level in well 209 rose 14 feet, and on May 24, 1969, the water level in the same well declined more

than 5 feet (Figure 2). Such large fluctuations may indicate small storage capacities and/or low permeabilities in portions of the limestone aquifer. Second, water levels in both wells do not recede gradually throughout the summer as in overburden wells, but instead drop sharply from the spring high, and throughout the summer fluctuate only slightly from the annual low. This rapid recession is a noticeable feature of the water-level recession curves for wells 123 and 209 shown in Figure 3.

In Precambrian Rocks

Well 230 is approximately 45 feet deep and is located in an area of paragneiss near Bannockburn. For that part of 1970 for which water-level records exist (parts of March, April and August are missing), the water level in the well remained fairly constant with the maximum amplitude of fluctuation shown to be only 2 feet. Highest water levels are indicated during spring and in November, and the lowest level during the year occurred at the end of September. Long-term analysis of water-level trends in the well must wait until such records are available.

Correlation of Ground-Water Levels with Streamflow

Streamflow consists of water derived from two main sources: (1) from direct surface runoff and (2) from ground water. Ground-water contribution to streamflow is termed 'base flow', and during prolonged periods of very little or no precipitation, streamflow may consist entirely of ground-water discharge.

The amount of base flow in a stream depends on many interrelated factors of geology and hydrology. One of the main factors, however, is the ground-water gradient adjacent to the stream; for a given soil type, the higher the gradient, the greater the base flow. In practice, however, it is difficult to determine actual ground-water gradients adjacent to streams, and the assumption is made that water-level fluctuations in wells reflect changes in these gradients. The problem is now one of correlating base flow with water levels in wells. Such correlations, if valid, will be useful in separating the base-flow component from streamflow hydrographs, in predicting low flows, and most important of all, in helping to understand the dependance of streamflows on ground-water discharge.

Relationships between base flow and ground-water levels are variable and depend to a large extent on hydrogeology, topography, and surface-water storage in individual sub-basins. In the present study, correlations of 1968, 1969 and 1970 streamflow and ground-water data in four sub-basins are discussed:

Catchment Area	Gauge No. (Map 2)	Geologic Environment of Catchment
Total Moira River Basin	02HL001	—glacial overburden —Palaeozoic limestone —Precambrian plutonic, metasedimentary and metamorphic rocks
Black River Sub-Basin	02HL003	—metavolcanic rocks
Skootamatta River Sub-Basin	02HL004	—plutonic rocks
Parks Creek Sub-Basin	02HL103	—thin drift cover on limestone bedrock

The base-flow values used in the correlations were obtained by subjective interpretation of streamflow recession curves. Base flow, or near base-flow conditions, were presumed to exist in the stream after a period of several precipitation-free days when streamflow had declined considerably from high flows. Because the correlation is established essentially on low-flow data, the regression curves cannot be reliably extrapolated to include flows higher than those shown on the curves (figures 5-8).

In all of the analyses, daily average water-level depths in selected wells were correlated with corresponding daily average base flows, and where possible, regression curves were drawn. These curves are indicated in figures 5, 6, 7 and 8.

The curves in Figure 5 were used to separate the streamflow hydrograph at station 02HL001 on the Moira River near Foxboro into direct surface and ground-water runoff as shown in Figure 12. The curves in figures 6, 7, and 8 are presented similarly to allow a separation of the hydrographs at station 02HL003 on the Black River, station 02HL004 on the Skootamatta River, and at station 02HL103 on Parks Creek. Through these separations, an estimate of the proportion of ground water in streamflow throughout the year can be obtained.

Water Level in Well 122 and Base Flow at Gauge 02HL001

Similar trends between the water-level hydrograph for well 122 and the streamflow hydrograph at Foxboro (gauge 02HL001) are apparent (figures 2 and 12). However, during summer, streamflow peaks are produced by relatively little rainfall, whereas water-level response in the well cannot be detected when rainfall is small.

Two regression curves correlating water levels in the well to base flow at Foxboro are shown in Figure 5; one curve is based on data obtained during the June to October period, when evapotranspiration *(ET)* is large, and the other on data gathered from November to May when *ET* is small. It is imperative to understand that the curves must not be used indiscriminately to predict base flow on the basis of ground-water levels alone. Neither is the extrapolation of the curves beyond the range of 5 to 12 foot water-level depths recommended.

The curves were used to aid base-flow separation at station 02HL001 shown in Figure 12. Detailed discussions of these curves will be made in the surface-water chapter, but a few comments on the validity of the resultant separation is in order. For summer flows the separation appears to be valid, but base-flow separation during winter months was complicated by frozen springs in stream valleys and by local thaws in areas with variable snow cover. Consequently, high ground-water levels during winter do not always correspond to large base flows and the rating curves could not be used exclusively by themselves for the hydrograph separation.

Water Level in Well 210 and Base Flow at Gauge 02HL003

Low flows in the Black River consist, in large part, of surface-water drainage from vast swampy areas in the sub-basin, and release of water from Lingham Lake.

Releases from storage in Lingham Lake are noticeable during low flows in the Black River. For example, opening the dam at the outlet of the lake on September 13, 1970, resulted in a significant increase in streamflow immediately afterwards. Similarly, storage of water behind the dam is noticeable as shown by the closing of the dam on June 27, 1970, which reduced streamflow in the Black River during the early part of July (Figure 12).

The correlation of low flows at gauge 02HL003 with water levels in well 210 is reasonably good for unregulated summer and fall low flows. The regression line in Figure 6 is probably not applicable during spring and winter periods.

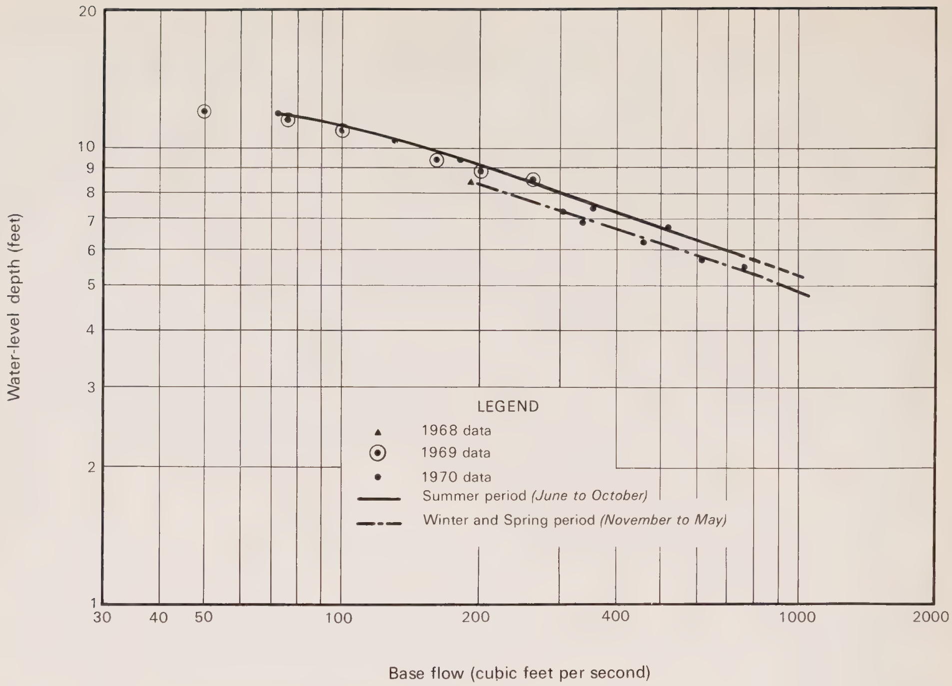


Figure 5. **Correlation of base flows at stream-gauging station 02HL001 on the Moira River near Foxboro, and the depth to water in observation well 122.**

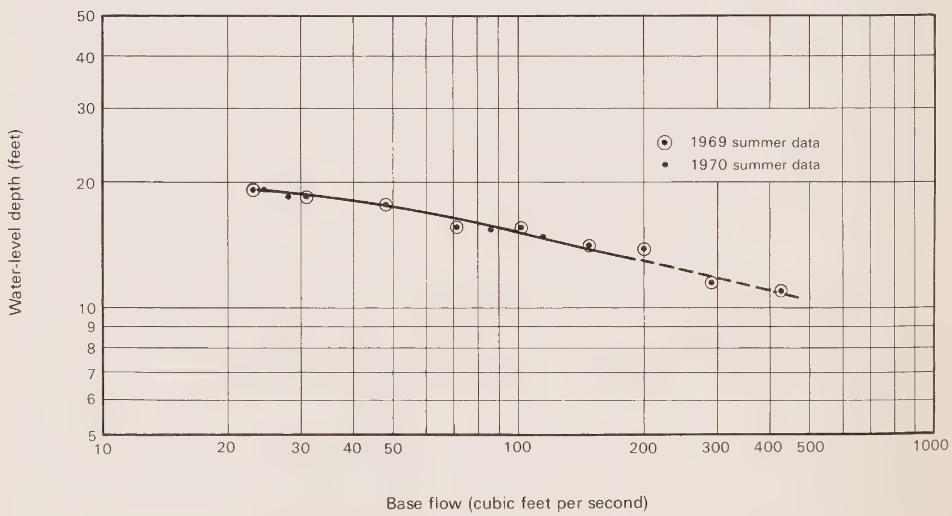


Figure 6. **Correlation of base flows at stream-gauging station 02HL003 on the Black River, and the depth to water in observation well 210.**

Water Level in Well 229 and Base Flow at Gauge 02HL004

Hydrographs of daily water-level fluctuations in well 229 and streamflow in the Skootamatta River during 1969-70 are similar (figures 2 and 12). However, as in other situations in the basin, flow in the Skootamatta River responds to small amounts of rain, whereas the water level in the well indicates a discernible response only when rainfall exceeds approximately 0.1 inch at the site.

A dam at the outlet of Skootamatta Lake complicates base flow/ground-water level correlations. For example, the large discharge recorded during September and October of 1969 is due to release of water from Skootamatta Lake, and streamflow during this time bears no relationship to the water level in well 229. Another complication is that low flow in the Skootamatta River consists, in part, of surface-water drainage from vast swampy areas in the sub-basins rather than solely of ground water. However, in spite of these complexities, the water levels in well 229 correlated fairly well with low flows in the river during 1969 and 1970. The regression line shown in Figure 7 suggests a relationship only between summer ground-water levels and base flow, and should not be employed in base-flow separations at other times of the year.

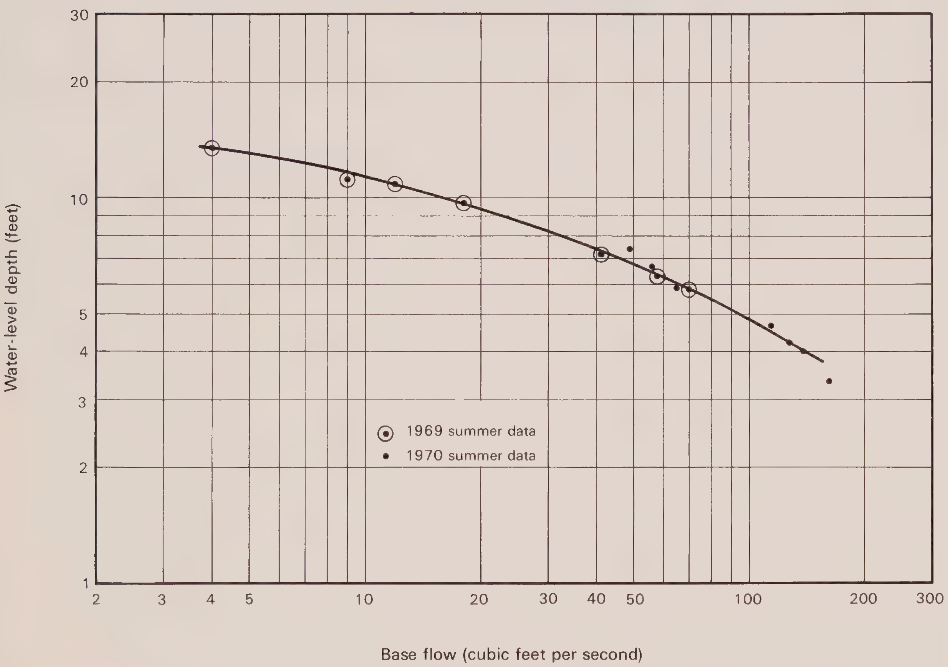


Figure 7. Correlation of base flows at stream-gauging station 02HL004 on the Skootamatta River, and the depth to water in observation well 229.

Water Level in Well 123 and Base Flow at Gauge 02HL103

The prominent peaks and lows in the ground-water and stream-flow hydrographs are concurrent and provide the main similarity between the two hydrographs during 1969 and 1970. The graphical correlation in Figure 8 between the water-level depths in well 123 and base flow in Parks Creek at gauge 02HL103 is defined by a regression line for only summer streamflows less than 100 cfs. A reliable correlation of data for other times of the year could not be obtained, probably for the same variety of reasons as outlined in previous discussions. The regression line is based on only two years of data, and additional data may modify the correlation or provide basis for yet another correlation applicable to higher streamflows.

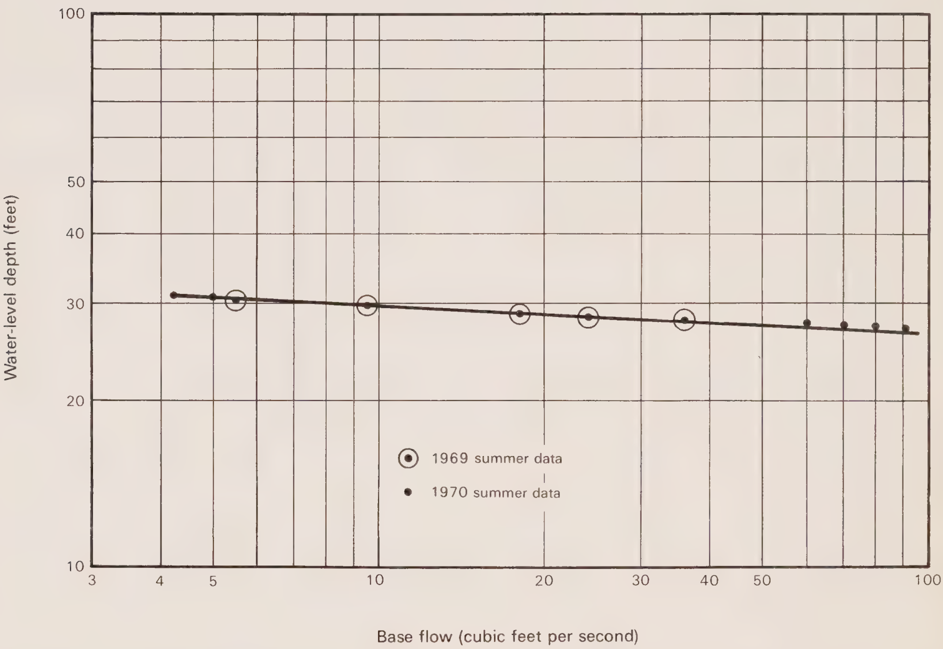


Figure 8. Correlation of base flows at stream-gauging station 02HL103 on Parks Creek, and the depth to water in observation well 123.

SURFACE WATER

Introduction

More than 200 billion gallons of surface water flow out of the Moira River basin annually. However, because the seasonal distribution of streamflow is irregular, conflicts of stream-water use often occur during periods of low flow; therefore, optimization of surface-water use in the basin requires the conservation and management of the resource through judicious regulation of water use and development.

The five largest streams in the watershed, the Moira, Black, Skootamatta and Clare rivers, and Parks Creek, were given particular attention in the analyses of surface-water data. Analyses and discussions of flows in these streams concentrate mainly on extreme flows in order to provide relevant information for relating available water in the streams to present and future water uses.

Field work consisted of measuring streamflows at 20 selected stations during the period June to September 1969, and sampling of 10 lakes and 11 streams during August 1969, for chemical analyses. Short-term streamflow data were extended to a common base period to compare flows and yields in the various sub-basins. In most cases, this involved linear correlation of short-term data with data from the nearest long-term station. In extending data for low-duration curves, the method described by Searcy (1958) was used.

Streamflow Instrumentation

There are eight streamflow recording stations in the Moira River basin (Map 2); four are operated by the Canada Department of the Environment and four by the Ontario Ministry of the Environment. Data collected by both agencies are published annually in *Surface-Water Data, Ontario* by the Inland Water Directorate, Canada Department of the Environment.

The oldest station in the basin is 02HL001 on the Moira River near Foxboro. This station was established by Ontario Hydro in 1915. It is also the farthest downstream station in the basin and monitors discharge for approximately 98 per cent of the watershed, or 1040 square miles. For discussion purposes, the discharge at this gauge is taken to represent the total flow from the watershed which is actually 1060 square miles in area.

Fourteen years of continuous discharge data (1956-1969) have been collected at streamflow stations 02HL003 on the Black River near Actinolite and 02HL004 on the Skootamatta River near Actinolite. However, streamflow data at the gauge on the Skootamatta River are incomplete during the period October 1957 to September 1958 and therefore only complete data in the eleven-year interval from 1959-1969 are analyzed. Streamflow data on the Moira River at Deloro has been gathered since 1965 and four years of complete data (1966-1969) are analyzed.

The gauges on the Black and Skootamatta rivers, and on Parks Creek near Latta (station 02HL103) record the total flows from each sub-basin. However, the gauge on the Clare River near Bogart (station 02HL102) records the discharge from only about 54 per cent of this sub-basin.

Streamflow data on the Moira River at stations 02HL101 near Tweed and 02HL104 near Thomasburg have not been analyzed because of discrepancies in data at both stations.

Supplementary streamflow data at 20 periodically measured stations (Map 2) were collected once a week during the period June to September 1969, to provide additional low-flow information. Inaccessibility prevented stream gauging of Partridge Creek, a major tributary of the Skootamatta River, and of Black River and its tributaries upstream of the Actinolite gauge.

Descriptions of Lakes, Streams and Swamps

There are more than 70 lakes in the watershed and most of them are in the northern sections of the basin (Map 1). Nineteen lakes have surface areas in excess of 100 acres (Table 2), and only Moira, Lingham, Skootamatta, and Stoco, the largest lakes in the basin, each exceed 500 acres. The combined area of these four lakes is approximately 7600 acres. Skootamatta Lake is the deepest, with depths in excess of 100 feet, whereas depths in the other three lakes do not exceed 50 feet (Ontario Department of Planning and Development, 1950).

Table 2. Lakes in the Moira River Basin with Surface Areas Greater Than 100 Acres

Lake	Area (acres)	Sub-basin
Wolf	110	Moira River above Streamflow Recording Station 02HL005 near Deloro
Jordan	140	
Jarvis	170	
Moira	2150	Moira River below Streamflow Recording Station 02HL005 near Deloro
Stoco	1390	
Lingham	2150	Black River
Joeperry	390	Skootamatta River
Pringle	350	
Skootamatta	1940	
Sheldrake	440	
Upper Partridge	120	
Merrill	380	
Little Merrill	140	
Whitefish	140	
Grimsthorpe	210	
Deerock	360	
Mellon	300	Clare River above Streamflow Recording Station 02HL103 near Bogart
Dry	110	Parks Creek
Lime	250	
Total Lake Area	11,240	

There are four large tributaries to the Moira River: the Black, Skootamatta and Clare rivers, and Parks Creek. Areas not covered by these four drainage systems are drained by smaller tributaries flowing directly into the Moira River and these make up about 40 per cent of the watershed. The Black and Skootamatta rivers combined drain approximately another 40 per cent, and the remaining 20 per cent of the basin is drained by the Clare River and Parks Creek. These drainage areas are shown on Map 1.

The northern parts of the basin are drained by the Moira (above Deloro), Black, Skootamatta and Clare rivers. The streambed gradients of these streams are relatively steep compared to those in the south (Figure 9) and the streams themselves consist of natural ponds, rapids and falls over long reaches as they flow directly on bedrock. Numerous on-stream ponds and peripheral swamps are a noticeable feature of the streams.

Extensive areas in the north are covered by continuous lowland swamps and marshes, with virtually all of the Clare River headwaters being covered by wetlands. Large continuous swampy areas also exist in the central portions of the Black and Skootamatta sub-basins where a myriad of small lakes and interconnected ponds are closely associated with the swamps. In many instances the ponds are nothing more than patches of open water in otherwise vegetated swampy lowlands.

Streams draining the southern portions of the watershed (tributaries of the Moira River below Deloro, and Parks Creek) have generally lower streambed gradients than those in the north, except for Chrysal Creek whose headwaters are on the steep moraine in the southwest, and Parks Creek in the vicinity of Marlbank (Figure 9). The extensive swampy areas so prevelant in the north are generally absent from the southern portions of the basin. Large sections of the lower reaches of the Moira River flow on limestone bedrock, while most of Parks Creek has its streambed directly on glacial drift.

Effects of Dam Regulation on Streamflow

Dams have been built at the outlets of five lakes: Lingham (B-1), Moira (M-2), Skootamatta (S-1), Stoco (M-3 and M-4) and Deerock (S-6). The locations of these dams are shown on Figure 28 and details of their use are presented in Table 12. The reservoirs behind the dams provide surface-water storage for streamflow augmentation, for retarding floods, and for enhancing recreational facilities on the lakes.

Until 1969, the Lingham Lake dam was the only one in the basin built specifically for storing water for streamflow augmentation. Water is stored in the lake during periods of high flow in the spring and is released gradually in summer and fall when natural flows in the Black River are usually at their lowest. Because of this gradual release of water, sudden increases in streamflow in the river are not common. In almost two years of continuous streamflow record for the Black River, only once (September 1970) was there a large, sudden increase in streamflow due to release of water from Lingham Lake (Figure 12).

Dams at the outlets of Moira, Stoco, and Skootamatta lakes are used primarily for controlling water levels in the lakes and their operations rarely affect streamflow noticeably. However, water from Skootamatta Lake is at times used for augmenting downstream flows, and at such times, noticeable increases in flow in the Skootamatta River do occur. For example, discharge in the Skootamatta River increased rapidly on September 10, 1969, and continued at a high level until October 13 (Figure 12). Because no heavy rains were recorded at Tweed to account for this rise, the high flows are attributed to water released from the lake.

Deerock reservoir on Partridge Creek was built to augment low flows in the Skootamatta River. It was completed in 1969 and has a storage capacity of 7500 acre-feet. The reservoir was designed to increase flows in the Skootamatta River by about 30 cfs during the summer.

In addition to the large dams already mentioned, there are numerous smaller ones throughout the basin, many of which are no longer in use. Those that are used have only minimal effects on downstream flows.

Variations In Streamflow

The analyses of annual mean, monthly mean, and daily mean discharges were undertaken to provide information on the variability of streamflows in the basin and to compare the yields from the main sub-basins in the watershed.

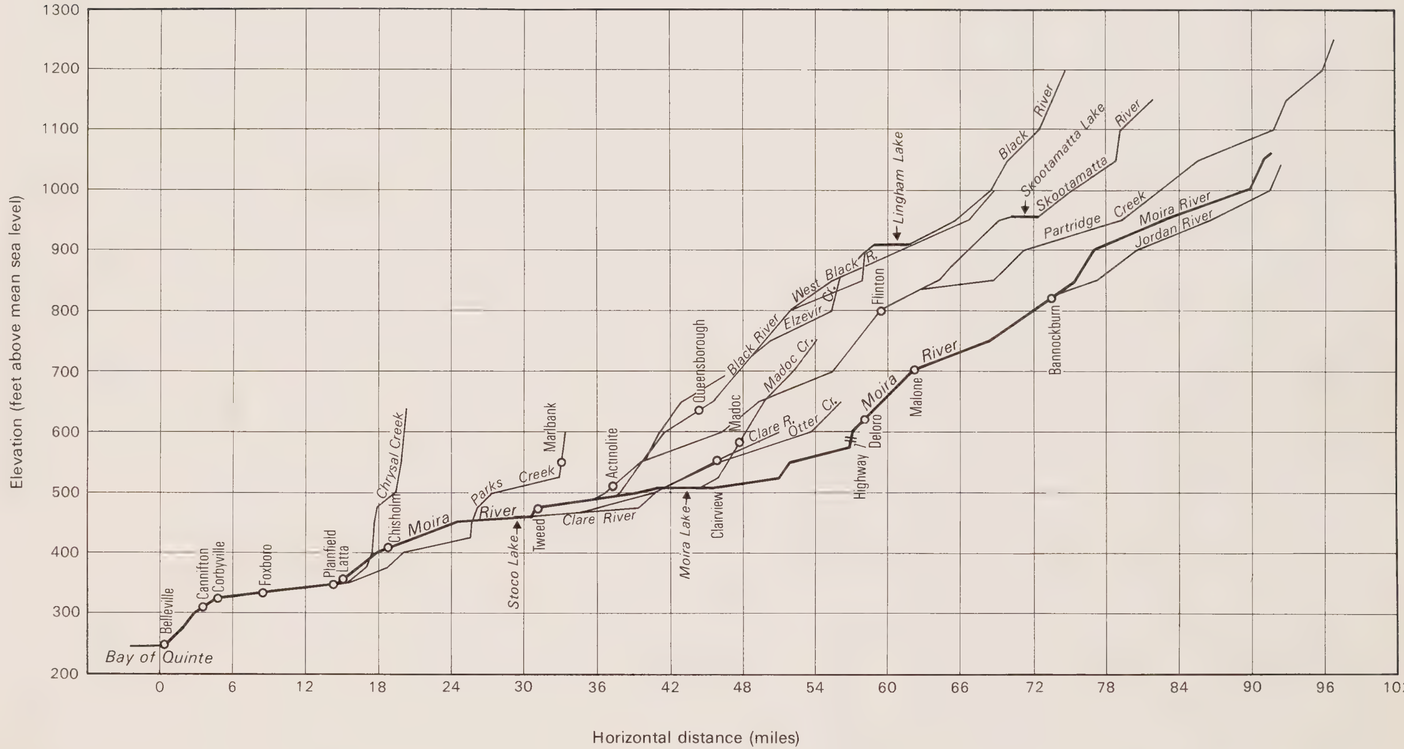


Figure 9. Stream-bed profiles, Moira River basin.

Discharge data for all recording stations were reviewed but due to the short period of record at some stations, annual and monthly discharge variations can only be presented for stations 02HL001 and 02HL005 on the Moira River near Foxboro and Deloro, 02HL003 on the Black River, and 02HL004 on the Skootamatta River. Daily streamflow hydrographs are presented for the four streams mentioned above, plus for Parks Creek at station 02HL103 and Clare River at station 02HL102.

Annual Mean Discharge

The hydrograph of annual mean discharges from the Moira River at the Foxboro gauge indicates a maximum mean flow of 1940 cfs in 1928 and a minimum of 522 cfs in 1931 (Figure 10). The mean annual discharge over the period of 54 years of data (1916-1969) has been 1040 cfs. The estimated mean annual discharges for stations on the Black and Skootamatta rivers, and on the Moira River near Deloro, for the same 54-year period are, 175 cfs, 305 cfs, and 120 cfs, respectively. The combined flow at these three stations accounts for approximately 58 per cent of the annual mean flow from the watershed. The Skootamatta River sub-basin, the single largest contributor, accounts for 29 per cent of the annual mean flow from the basin.

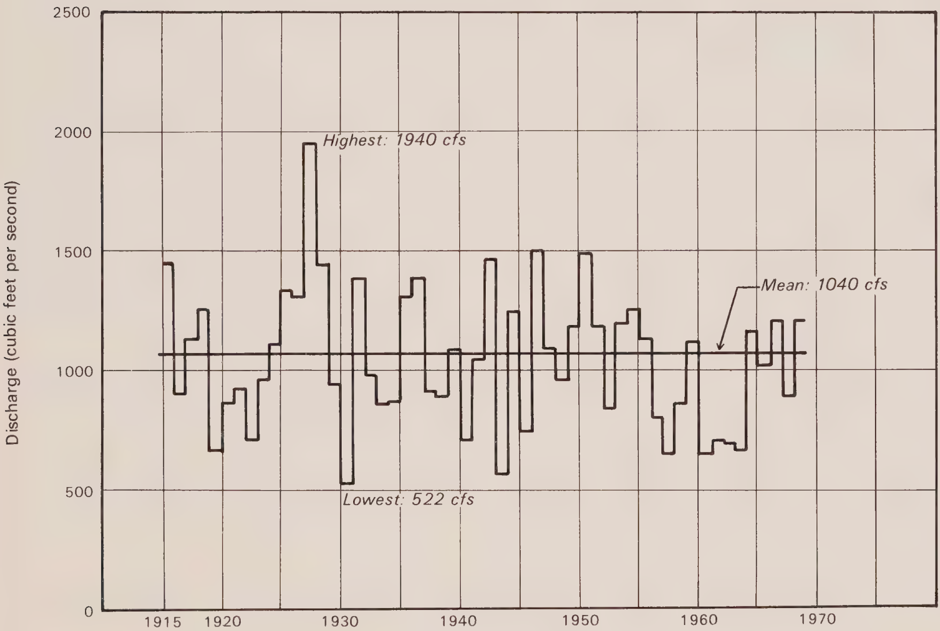


Figure 10. Hydrograph of annual mean discharges for the 54-year period 1916-1969, at gauging station 02HL001 on the Moira River near Foxboro.

Monthly Mean Discharge

Monthly mean discharges for the watershed vary widely throughout the year, as well as from year to year. Highest monthly flows in the Moira River at Foxboro have occurred in April and the lowest in September (Figure 11; Table 21 in Appendix D). About 62 per cent of the annual basin discharge has occured during the spring months of March, April and May, while less than 5 per cent of the annual volume has been provided by flows during the summer months of July, August and September. It is interesting to note that while the Black River sub-basin is little more than one half the area of the Skootamatta, its mean and median flows for August and September are about three times greater than those in the Skootamatta River (tables 22 and 23 in Appendix D). These high summer flows in the Black River probably result, in large part, from regulation of the Lingham Lake dam.

A large proportion of the flow in the Moira River during late summer and early fall is contributed by the Black and the Skootamatta rivers, the only two streams whose flows are regulated significantly. The average contribution by the Black River (1966-1969) was largest during August and September (Table 3) when flows out of the sub-basin were 32.5 per cent and 42.2 per cent of the total flow from the watershed; the annual mean contribution was 17.2 per cent. For the Skootamatta River (1966-1969) the largest contributions of 37.0 per cent and 39.6 per cent occurred in September and October, and the annual mean averaged 29.6 per cent. The average contribution from the northern part of the Moira River (above Deloro) was 11.9 per cent, and the monthly contributions have ranged from 5.1 per cent in September to 18.9 per cent in October.

Daily Mean Discharge

Hydrographs of daily discharges and precipitation (at Tweed) illustrate streamflow fluctuations and their relationship to precipitation events during 1969 and 1970 at six streamflow recording stations in the watershed (Figure 12). In addition, the hydrograph at station 02HL001 is separated into direct surface runoff and base flow to indicate the approximate relationship between these two components as part of total streamflow. Daily mean streamflow fluctuations are directly dependant on precipitation. During the summer, local precipitation produces daily streamflow peaks shown on the six hydrographs. During the winter months, precipitation, when in the form of snow, does not produce daily streamflow peaks. Peaks during the winter are the result of snowmelt produced by periods of thaw. There are generally few daily peaks during the months of January, February and March.

The hydrographs of daily mean discharges in the Black River near Actinolite and in the Skootamatta River near Actinolite indicate periods of high flows which cannot be attributed to precipitation. These high flows, in September and October 1970 in the Black River, and in September and October 1969 in the Skootamatta River, are suspected to be due to releases of water from upstream storage: from Lingham Lake in case of the Black River, and from Skootamatta Lake for Skootamatta River. Artificial storage for streamflow augmentation does not exist in case of the Moira River upstream of Deloro, Parks Creek upstream of Latta or Clare River upstream of Bogart.

Low daily mean discharges are the result of prolonged periods of zero precipitation, and two streams are especially susceptible to drying up in the latter part of the summer if rainfall has been low. One is the Clare River near Bogart, which had no flow in it for several days in September 1970. The other stream is Moira River near Deloro which had also virtually no flow in it during the same time. Rainfall during August and the early part of September in 1970 was very low (Figure 12).

At the Foxboro gauge the daily mean streamflow of 1196 cfs in 1969 consisted of approximately 22 per cent ground water. In 1970, ground water made up about 23 per cent of the daily mean streamflow of 886 cfs. In these two years the largest proportion of ground water

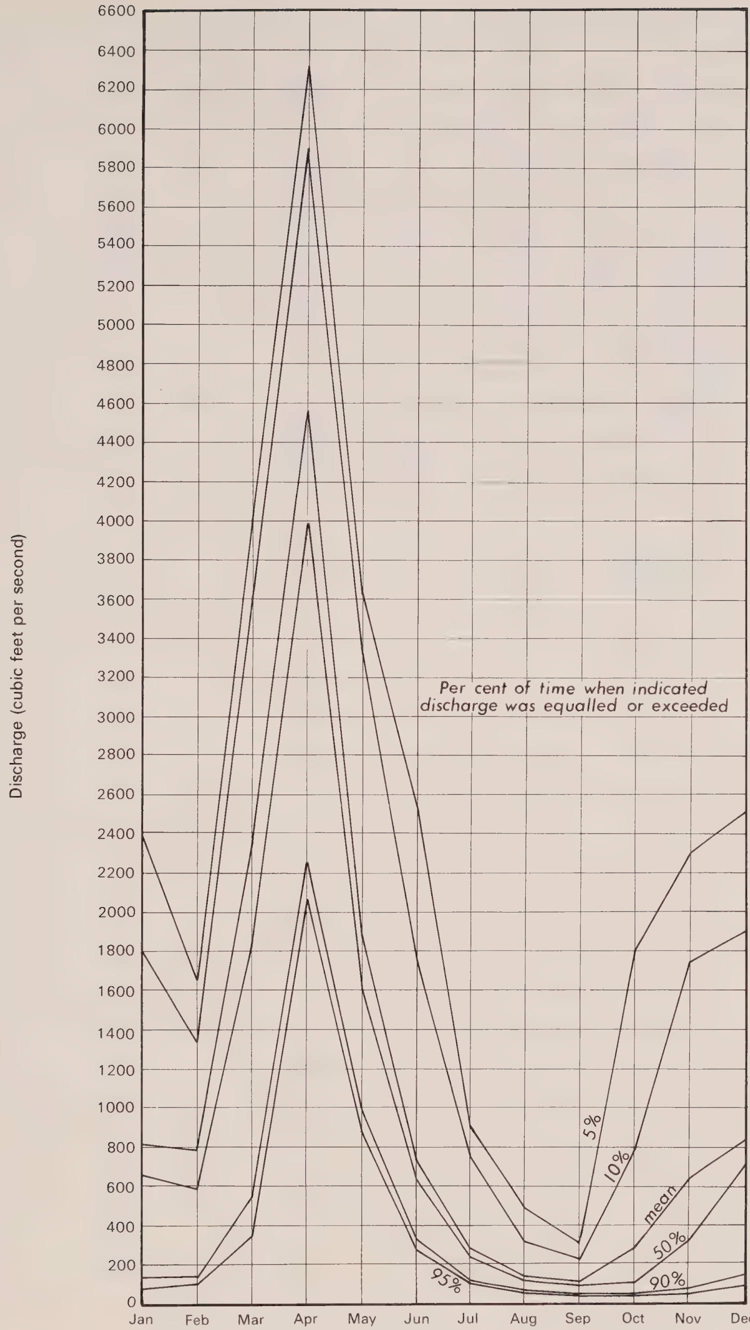


Figure 11. Curves of mean monthly discharges that were equalled or exceeded at selected percentages of time at gauging station 02HL001 on the Moira River near Foxboro (1916-1969 data).

Table 3. Mean Annual and Monthly Discharges at Streamflow Recording Stations in the Moira River Basin, Based on Four Years of Data (1966-1969)

Station		Mean Discharge (q) in cfs and Per cent (%) of Total Discharge Out of Basin												
		Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
02HL001 (Moira River near Foxboro)	q	1070	1000	994	2010	2970	1640	770	387	142	111	321	974	1590
	%	100	100	100	100	100	100	100	100	100	100	100	100	100
02HL003 (Black River)	q	184	159	164	338	421	296	116	76	46.1	46.8	78.8	203	260
	%	17.2	15.9	16.5	16.8	14.2	17.0	15.1	19.6	32.5	42.2	24.5	20.9	16.3
02HL004 (Skootamatta River)	q	317	293	264	563	875	511	199	105	30.5	41.1	127	340	456
	%	29.6	29.3	26.6	28.1	29.5	31.1	25.8	27.2	21.5	37.0	39.6	35.0	28.7
02HL005 (Moira River near Deloro)	q	127	99	109	246	374	199	72.6	34.4	7.9	5.7	60.6	122	197
	%	11.9	9.9	11.0	12.2	12.6	12.2	9.4	8.9	5.6	5.1	18.9	12.5	12.4

Table 4. Annual Minimum Flows and Corresponding Yields at Three Streamflow Recording Stations in the Moira River Basin

Average Recurrence Interval (T) (years)	Duration (days)	Moira River		Black River		Skootamatta River	
		Min. Flows (Q) (cfs)	Min. Flow Yields (cfs/sq mi)	Min. Flow (Q) (cfs)	Min. Flow Yields (cfs/sq mi)	Min. Flow (Q) (cfs)	Min. Flow Yields (cfs/sq mi)
2.33	1	38.3	0.038	11.5	0.074	4.9	0.018
	7	47.0	0.045	16.0	0.103	6.0	0.022
5	1	25.0	0.024	5.6	0.036	3.1	0.011
	7	33.3	0.032	9.8	0.063	3.8	0.014
10	1	19.5	0.019	3.2	0.021	2.3	0.008
	7	27.0	0.026	7.1	0.040	2.8	0.010
20	1	16.8	0.016	2.0	0.013	1.9	0.007
	7	23.3	0.022	5.5	0.036	2.2	0.008
Index of Variation (I_v)		2.3		5.8		2.6	

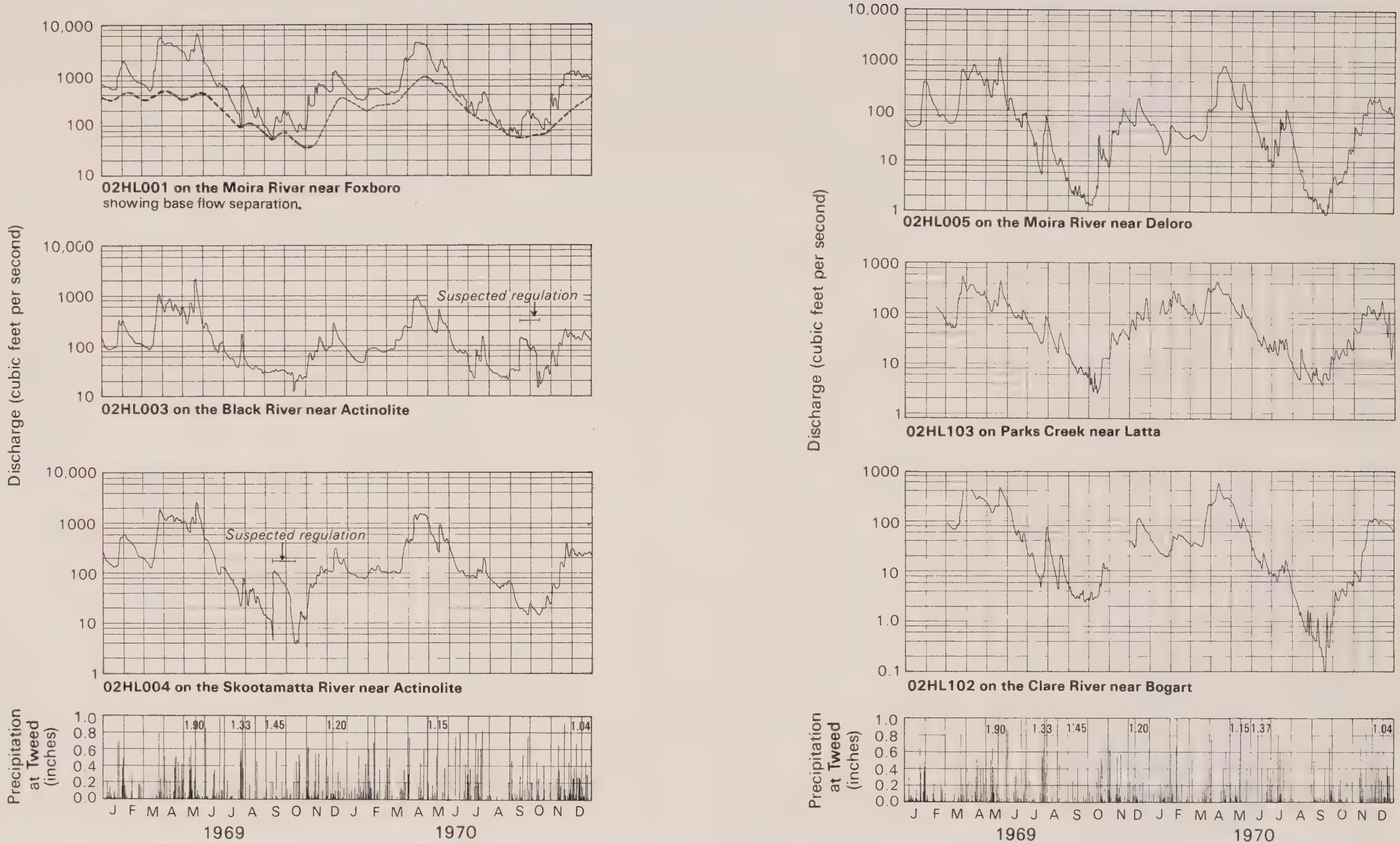


Figure 12. Hydrographs of daily mean discharges for streamflow recording stations in the Moira River basin during 1969 and 1970.

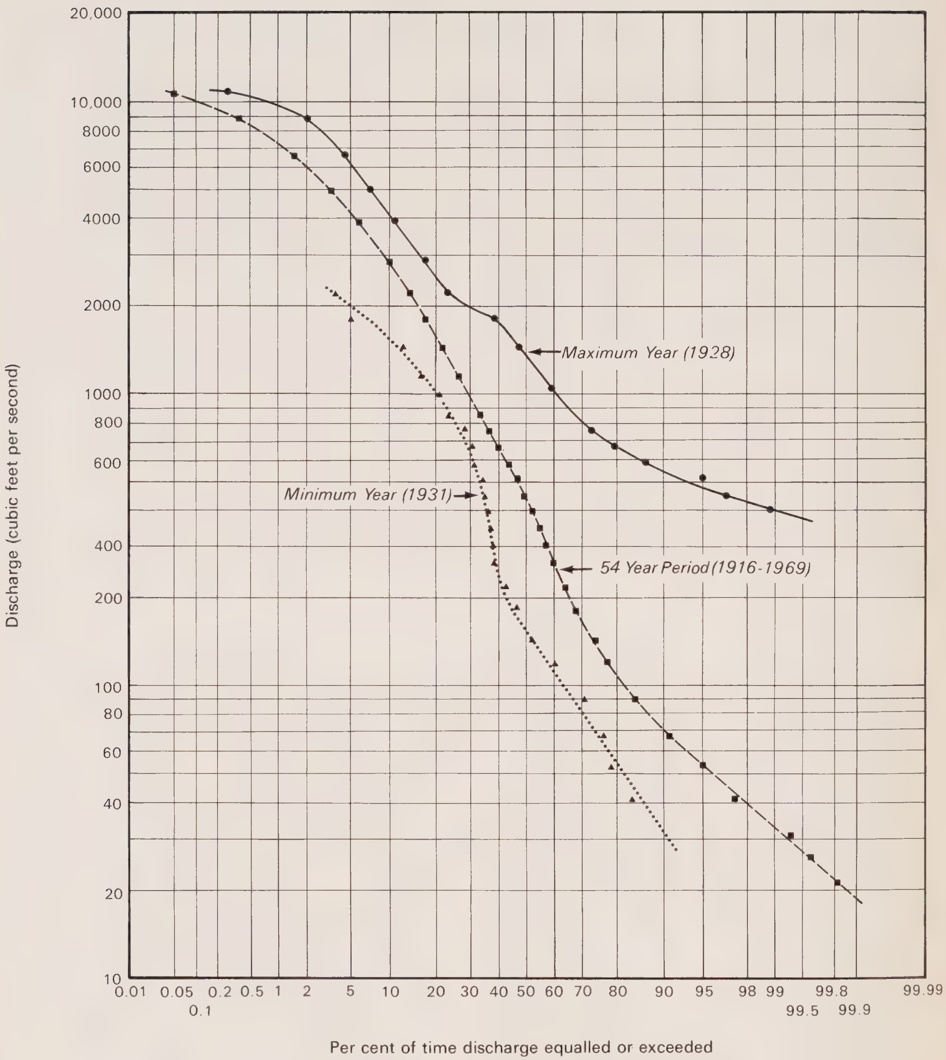


Figure 13. Duration curves of daily discharges at gauging station 02HL001 on the Moira River near Foxboro (1916-1969 data).

occurred during the months of August, September, and November, when as mush as 85 per cent of the total discharge out of the basin was base flow. Lowest proportions have occurred during the spring when usually less than 10 per cent of the total streamflow has been ground water.

In spite of the high proportions during late summer and fall, the volume of ground-water discharge to streams in many parts of the basin is relatively small, and as such, many small tributaries have very low flows during these times.

For all practical purposes, the amount of ground-water discharge to streams is expected to be significant only where streams traverse extensive areas of sand and gravel, as for instance on the sand plain on which large sections of Chrysal and Palliser creeks are located. Low flow in streams in other parts of the watershed is suspected to be due in large part to the depletion of surface-water storage from lakes and swamps, rather than solely from ground-water storage.

Flow Duration

Flow-duration analyses were carried out to investigate the effects of ground- and/or surface-water storage on streamflow. These effects can be estimated by analyzing the changes in slope in the different sections of the flow-duration curve; in theory, a flattened slope in the low-flow section of the curve is evidence of large contributions from ground- and/or surface-water storage, while a steep slope indicates negligible yields from storage. In the high-flow portion of the curve, a flattening of the slope suggests that high flows result largely from snowmelt, and the same is true for a stream with a large amount of flood-plain storage or a stream draining vast areas of swampy land. For a more comprehensive discussion of flow-duration curves, their derivation, interpretation and use, the reader is referred to the publication by Searcy (1959).

Flow-duration curves of daily discharges were prepared for six gauging stations in the basin: the Moira River near Foxboro, the Black and the Skootamatta rivers, the Moira River near Deloro, Clare River, and Parks Creek.

Moira River near Foxboro

The flow-duration curve for gauge 02HL001 on the Moira River near Foxboro was derived from 54 years (1916-1969) of continuous records (Figure 13). Upstream flows are regulated but the effects of regulation are not evident on the curve.

The steep slope in the low-flow end of the curve indicates that low-flow contributions from ground- and surface-water storage are generally small. Although there is some storage in lakes and swamps in the northern sections of the basin, the storage is not significant enough to provide low flow for extended periods of time at Foxboro. However, the flattening of the slope at the high-flow section of the curve suggests that this storage has a tendency to moderate peak flows.

Flow-duration curves for years of maximum (1928) and minimum (1931) annual flows are also shown for purposes of comparison with the long-term curve.

Black River

The flow-duration curve for gauging station 02HL003 on the Black River (Figure 14) is based on 14 years (1956-1969) of data. These data were extended to cover the period from 1916 to 1969 to coincide with the period of streamflow recorded at the Foxboro gauge. The effect of streamflow regulation by Lingham Lake dam is indicated as a ‘hump’ on the curve

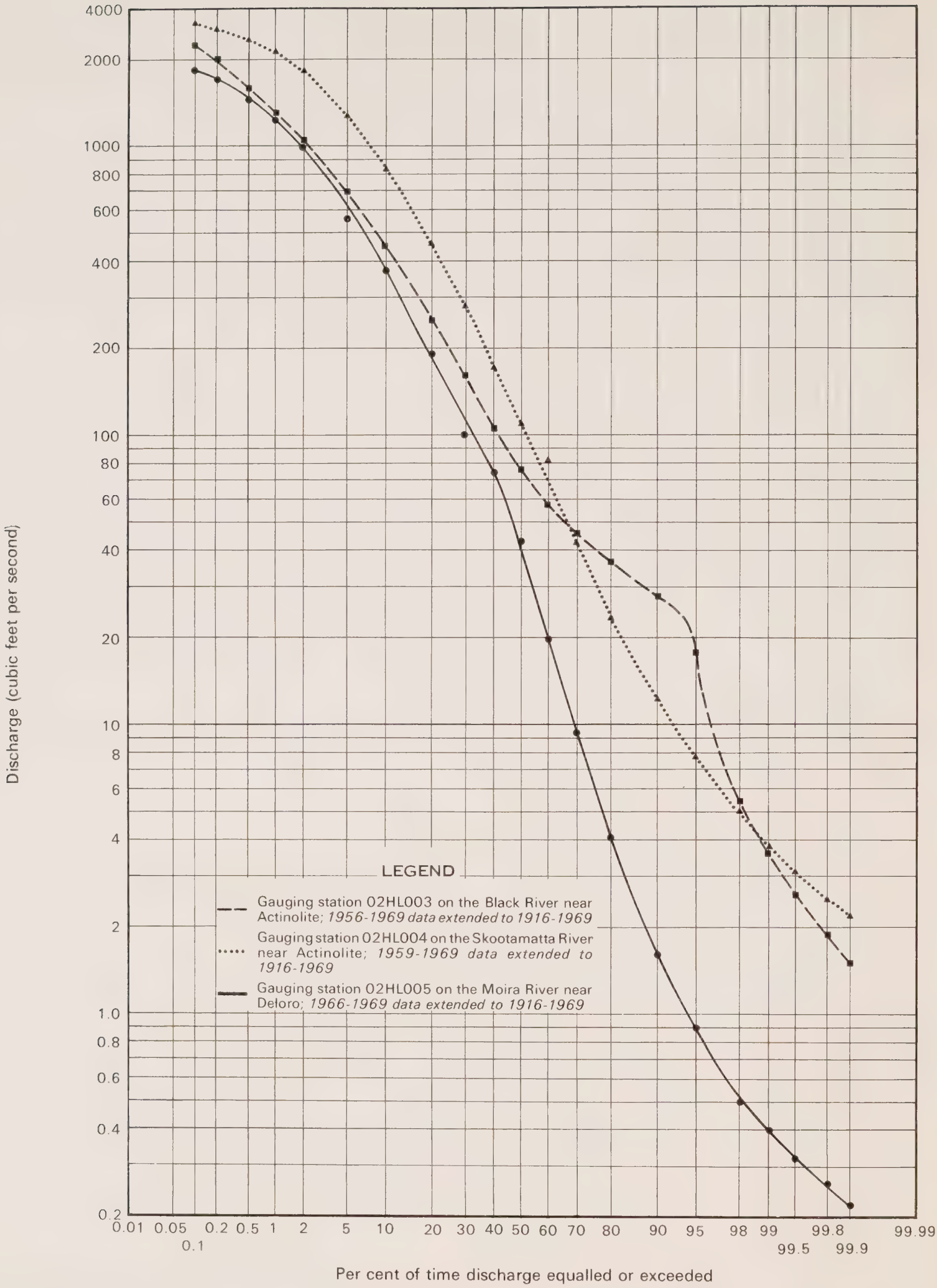


Figure 14. Duration curves of daily discharges at gauging stations 02HL003 on the Black River, 02HL004 on the Skootamatta River, and 02HL005 on the Moira River near Deloro (variable periods of data).

in the 20 cfs range. This anomaly is due to release of water from the lake, thus rapidly increasing streamflow. No decreases are indicated on the curve to correspond with storage of water.

The steep slope in the low-flow section of the curve suggests that water derived from ground- and/or surface-water storage is not sufficient to maintain significant flows in the stream. Similarly, the steep slope in the upper end of the curve suggests that very little storage capacity in the lakes and swamps is utilized to moderate peak flows.

Skootamatta River

The flow-duration curve for gauging station 02HL004 on the Skootamatta River (Figure 14) is based on 11 years (1959-1969) of continuous data which were extended to cover the period from 1916 to 1969. Periodically during the summer and fall, flows in this stream are augmented by water released through the Skootamatta Lake dam. However, the effects of this augmentation are not evident on the curve because of either few periods of regulation or insignificant quantities released from storage.

The change to a flatter slope in the low-flow section of the curve suggests that storage in the numerous lakes, swamps, and in the ground contributes to low flow. The relatively flat slope in the upper end of the curve indicates that this storage is also effective in moderating high flows.

Moira River near Deloro

The flow-duration curve for this station (Figure 14) is based on only four years (1966-1969) of data, which were extended to cover the period 1916 to 1969.

The generally steep slope throughout the curve indicates that this sub-basin has very little ground- and surface-water storage to maintain streamflow during dry periods, or to retard peaks during storm runoff.

Clare River and Parks Creek

The daily flow-duration curves for gauging station 02HL102 on the Clare River and 02HL103 on Parks Creek (Figure 15) are based on only two years (1969-1970) of partial streamflow data, which were extended on the basis of the five years of data available at the Deloro gauge (02HL005), to cover the period from 1966 to 1970. A longer period of extension was not possible because of the short-term, partial data available at the two stations.

The steep lower slope of the curve for the Clare River suggests that only very little streamflow is derived from storage during periods of low flow. However, a somewhat flatter slope at the high-flow end of the curve suggests that storage in lakes and swamps does occur at times of high flows, thus moderating flood peaks from this sub-basin. The flow-duration curve for Parks Creek indicates similar effects of storage on streamflows; very small contributions to low flows, but some storage capacity to slightly moderate high flows.

Ninety Per Cent Low Flows

Daily flows equalled or exceeded 90 per cent of the time (on the flow-duration curves) were chosen to represent low flows in the watershed. These flows, shown on Map 8, illustrate the distribution of low flows and their range of values throughout the basin. The low flow at

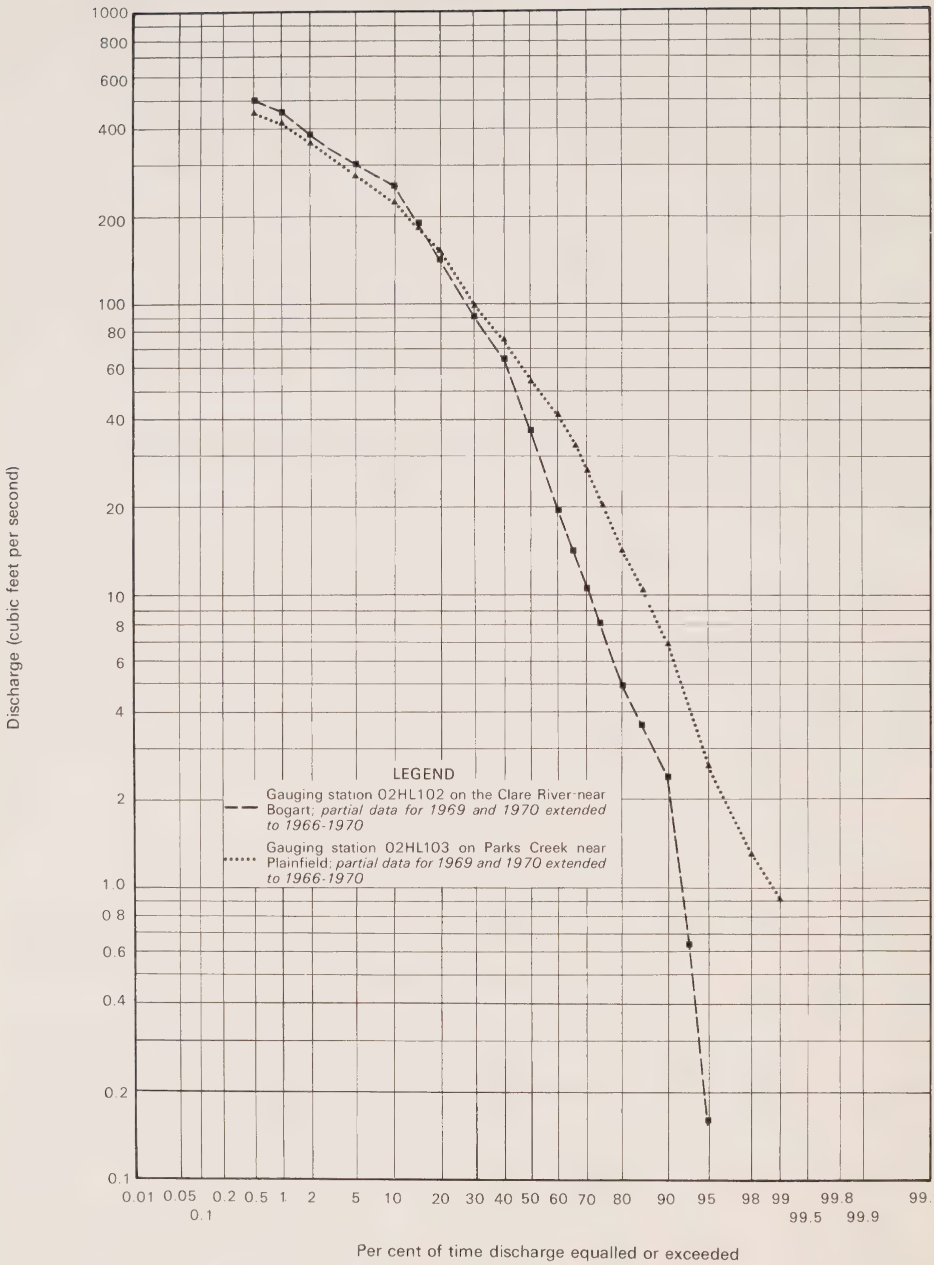


Figure 15. Duration curves of daily discharges at gauging stations 02HL102 on the Clare River and 02HL103 on Parks Creek (variable periods of data).

each streamflow recording station was taken directly from the flow-duration curve for the station, while for the periodically gauged stations with no flow-duration curve, the flows were estimated on the basis of the average five lowest flows measured at each station according to the following relationship:

$$F_{90} = \frac{F \times F'_{90}}{F'}$$

F = average of five daily lowest flows measured at periodically gauged stations
F' = average of five daily mean flows at long-term gauging stations on concurrent days as those used to calculate F
F_{90} = 90 per cent low flow at periodically gauged station
F'_{90} = 90 per cent low flow at nearest long-term gauging station (obtained from the flow-duration curve for the station)

The 90 per cent flows in all stream sections, except in the lower reaches of the Moira, the Black, and the Skootamatta rivers, are less than 10 cfs. In most headwater tributaries the 90 per cent daily discharges are less than 1 cfs. The flow in the Moira River above the Black River confluence is less than 5 cfs. Immediately downstream of this confluence, flow in the Moira River is more than 30 cfs and eventually increases to more than 60 cfs at the Foxboro gauge.

Minimum-Flow Frequencies and Yields

Annual minimum discharge frequencies are analyzed to indicate variations in low flow at each gauging station and to compare low-flow yields from the different sub-basins in the watershed. The variations in low flow are indicated by an *index of variation,* defined as $Q_{2.33}/Q_{20}$ where $Q_{2.33}$ is the annual 1-day low flow for an average recurrence interval *(T)* of 2.33 years, and Q_{20} is the annual 1-day low flow for $T=20$ years. These values were obtained from figures 16-18. Prior to calculating these indices for the Black and the Skootamatta rivers, the data at each station were extended to the same 54-year base period (1916-1969) as that for the Foxboro gauge.

Frequency curves were prepared for stations 02HL001 on the Moira River, 02HL003 on the Black River, and 02HL004 on the Skootamatta River, and each set of curves is discussed in subsequent sections. The minimum discharges were averaged for commonly used durations ranging from 1 to 180 consecutive days. The 1- and 7-day low flows, for example, can be associated with uses such as sewage dilution and water supply; the 30- and 90-day low flows can be associated with design criteria for projects requiring constant flow throughout the summer, as for example the Deerock Reservoir. Low flows for durations of 180 days are useful for projects whose design criteria depend on a total annual flow, as for example the proposed reservoir on the Moira River near Bend Bay.

Low-flow yields for recurrence intervals from 2.33 years to 20 years are usually the highest at gauging station 02HL003 on the Black River, and lowest at station 02HL004 on the Skootamatta River (Table 4). For example, the mean 1-day low-flow yield for $T=2.33$ years at the gauge on the Black River has been approximately twice that at the Foxboro gauge, and 4 times the yield at the gauge on the Skootamatta River.

Moira River near Foxboro

The minimum daily discharge on record at this gauge, over the 54-year period of record (1916-1969), has been 15.0 cfs, which has an average recurrence interval of 40 years (Figure 16); the 90 per cent low flow of 61 cfs shown on Map 8 has recurred on an average of once every 1.47 years.

In comparing the indices of variation of the three gauges, the annual low-flow variations at this station are considerably less than on the Black River, and virtually the same as on the Skootamatta River.

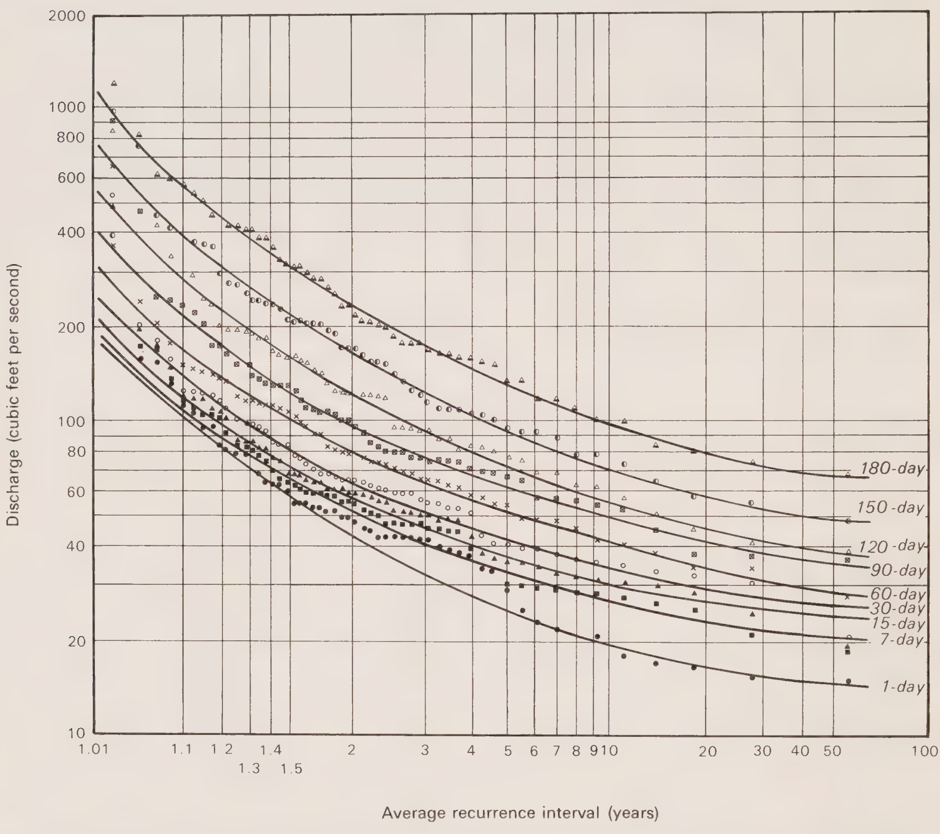


Figure 16. Frequency curves of annual minimum discharges at gauging station 02HL001 on the Moira River near Foxboro (1916-1969 data).

Black River

Zero daily discharges in the Black River near Actinolite have been recorded on three consecutive days—September 22, 23, and 24, 1960. However, zero flows in the stream are not a common occurrence as annual 1-day minimum flows have more commonly ranged from 1 to 50 cfs (Figure 17).

Annual minimum flows in the Black River vary more than in the Moira and the Skootamatta rivers; the index of variation is 5.8 as compared to 2.3 and 2.6 for the other two streams. This higher index may be due, in part, to regulation during low flows by the Lingham Lake dam.

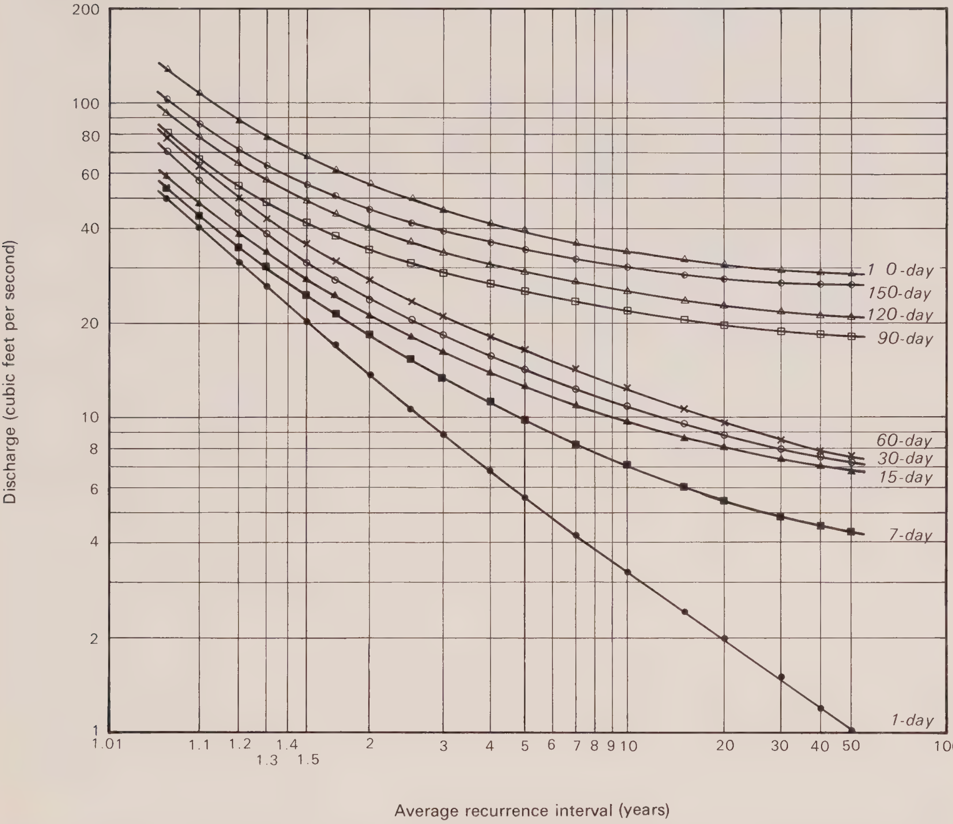


Figure 17. Frequency curves of annual minimum discharges at gauging station 02HL003 on the Black River (1956-1969 data extended to cover the period 1916-1969).

Skootamatta River

The lowest flow recorded at this gauge over 11 years of complete records (1959-1969) is 0.6 cfs; however, flows this low are rare and no recurrence interval can be assigned to them since they are beyond the range of the 1-day curve shown in Figure 18.

The index of variation of 2.6 suggests that annual minimum flows do not vary as widely as those at the neighbouring gauge on the Black River, but the variations are close to those on the Moira River at Foxboro. The relatively small variation is probably due to water derived from surface- and ground-water storage in the sub-basin during low flows.

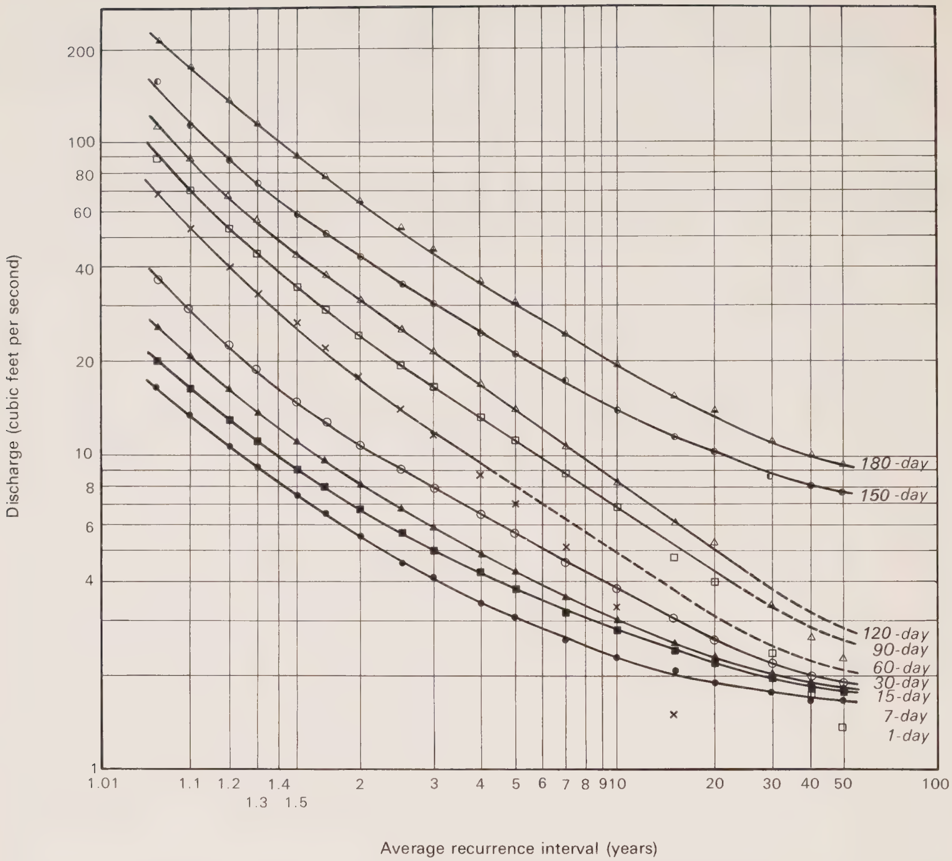


Figure 18. Frequency curves of annual minimum discharges at gauging station 02HL004 on the Skootamatta River (1959-1969 data extended to cover the period 1916-1969).

Maximum-Flow Frequencies and Yields

Annual maximum flows were analyzed to investigate the variations in the maximum discharges throughout the basin, and to compare yields during high flows from the three main sub-basins in the watershed with the longest streamflow records. The variations in high flows are measured by the *index of variation,* defined as $Q_{50}/Q_{2.33}$ where Q_{50} is the annual 1-day high flow with an average recurrence interval of 50 years, and $Q_{2.33}$ is the annual 1-day high flow for $T=2.33$. These values were obtained from figures 19-21. A large index indicates a large variation.

Frequency curves for annual maximum 1- and 7-day discharges were prepared for gauging stations 02HL001 on the Moira River near Foxboro, 02HL003 on the Black River and 02HL004 on the Skootamatta River. The maximum 1-day flow is often used as a criteria in design of flood control structures when instantaneous discharge peaks are not available, while the 7-day flows represent extended flood flows, as in compound floods. Data for stations on the Black and Skootamatta rivers were extended to the same 54-year period (1916-1969) as the period of record at the Foxboro gauge.

Maximum flows in the watershed usually occur in the spring months of March and April, but high flows can occur any time during the summer when they are caused by storm runoff. However, high summer discharges are generally lower than those in the spring.

The maximum-flow indices of variation in each of the three basins are similar, with an index of 1.3 for the Foxboro gauge, 1.5 for the gauge on the Skootamatta River, and 1.6 for the gauge on the Black River (Table 5). The maximum-flow yields are also similar; the mean annual 1-day yield ranged from 7.3 cfs per square mile above the Foxboro gauge, to 10.7 cfs per square mile above the gauge on the Black River.

Moira River near Foxboro

The maximum 1-day flow at this gauge, over the 54-year period (1916-1969) of record, was 12,400 cfs (March 31, 1936); this flow has an average occurrence interval greater than 50 years (Figure 19). However, the variation of annual maximum flows is not large; the 10-year, 1-day high flow is 10,800 cfs as compared to 11,800 cfs for the 20-year flow (Table 5).

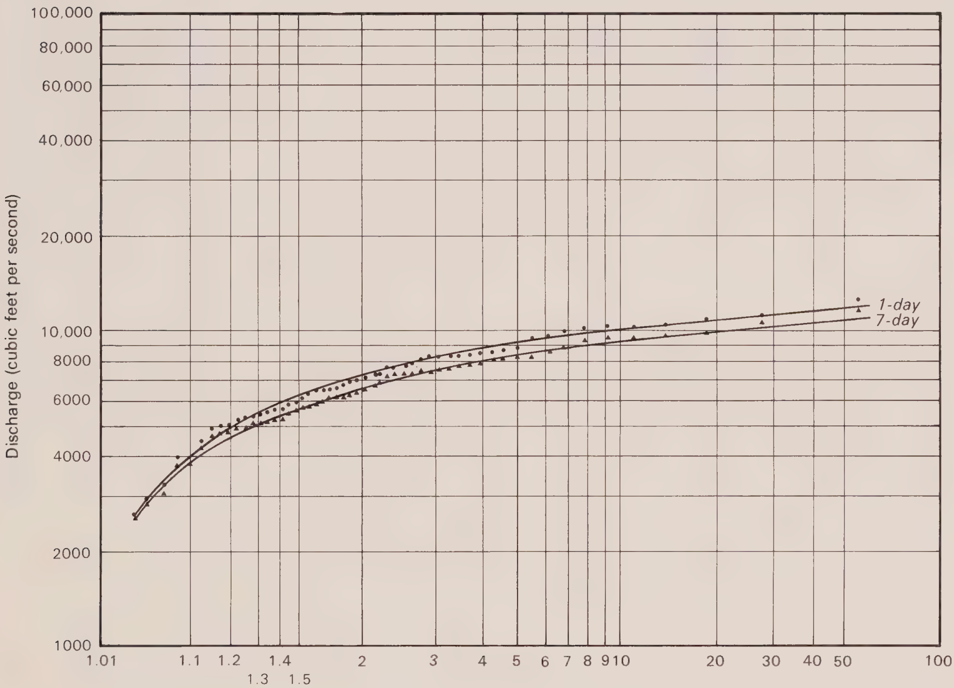


Figure 19. Frequency curves of annual maximum discharges at gauging station 02HL001 on the Moira River near Foxboro (1916-1969 data).

Table 5. Annual Maximum Flows and Corresponding Yields at Three Streamflow Recording Stations in the Moira River Basin

Average Recurrence Interval (T) (years)	Duration (days)	Moira River		Black River		Skootamatta River	
		Min. Flow (Q) (cfs)	Min. Flow Yields (cfs/sq mi)	Min. Flow (Q) (cfs)	Min. Flow Yields (cfs/sq mi)	Min. Flow (Q) (cfs)	Min. Flow Yields (cfs/sq mi)
2.33	1	7620	7.3	1660	10.7	2400	8.7
	7	6950	6.7	1260	8.1	2060	7.5
5	1	10100	9.7	2200	14.2	3050	11.1
	7	9250	8.9	1670	10.8	2700	9.8
10	1	10800	10.4	2360	15.2	3270	11.9
	7	4900	9.5	1800	11.6	2880	10.5
20	1	11800	11.3	2600	16.8	3550	12.9
	7	10800	10.4	1950	12.6	3120	11.3
Index of Variation (I_v)		1.3		1.6		1.5	

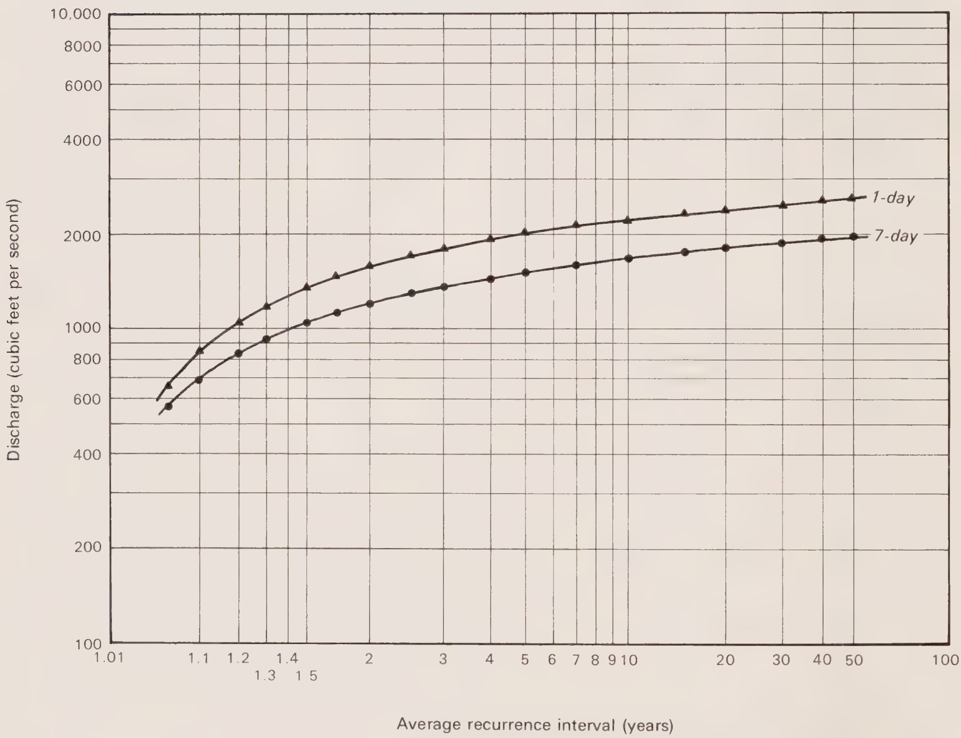


Figure 20. Frequency curves of annual maximum discharges at gauging station 02HL003 on the Black River (1956-1969 data extended to cover the period 1916-1969).

Black River

Only 14 years of record exist at this gauge (1956-1969) and the maximum daily flow recorded during this period was 2310 cfs, which occurred on May 20, 1969. On the 1-day frequency curve shown in Figure 20, this flow will recur on the average of once every 10 years.

The variation of annual maximum flows at the gauge on this stream is similar to that for gauges on the other two streams, but the maximum flow yields, over recurrence intervals from 2.33 years to 20 years (Table 5), are consistently higher. These higher yields may be partially due to lower storage capacities to moderate peak flows.

Skootamatta River

Only 11 years of complete daily records (1959-1969) have been collected at this station. During this period, the maximum daily flow of 2660 cfs was recorded on May 20, 1969, which is the same day on which the maximum flow occurred in the Black River. This flow has an average recurrence interval of only 3.8 years in this river (Figure 21).

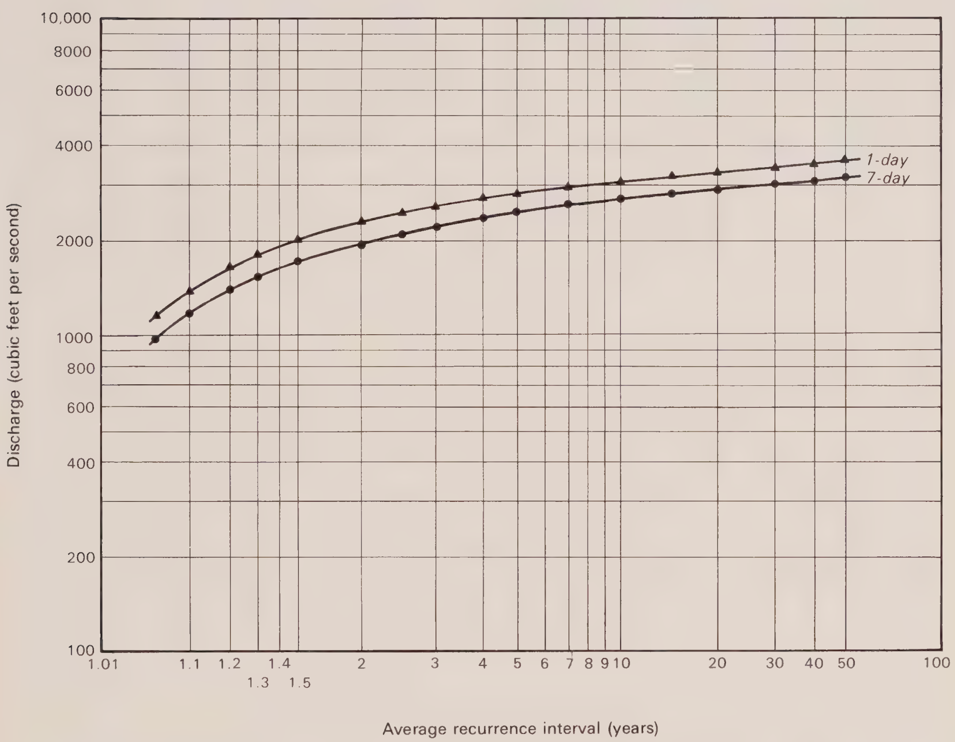


Figure 21. Frequency curves of annual maximum discharges at gauging station 02HL004 on the Skootamatta River (1959-1969 data extended to cover the period 1916-1969).

Storage and Dependable Flows

The relationship between storage and discharge at each long-term gauging station is presented to allow the determination of storage requirements in order to maintain various dependable flows downstream. The resulting curves (Figure 22) relate storage to discharge for an average recurrence interval of 5 years, and were derived from low-flow frequency mass curves shown in figures 36 to 38 in Appendix D.

With no artificial storage provisions on the streams (required storage = 0), the dependable flows that can be expected ($T = 5$) are: 38 cfs for the Moira River at Foxboro, 11 cfs for the Black River, and 5 cfs for the Skootamatta River.

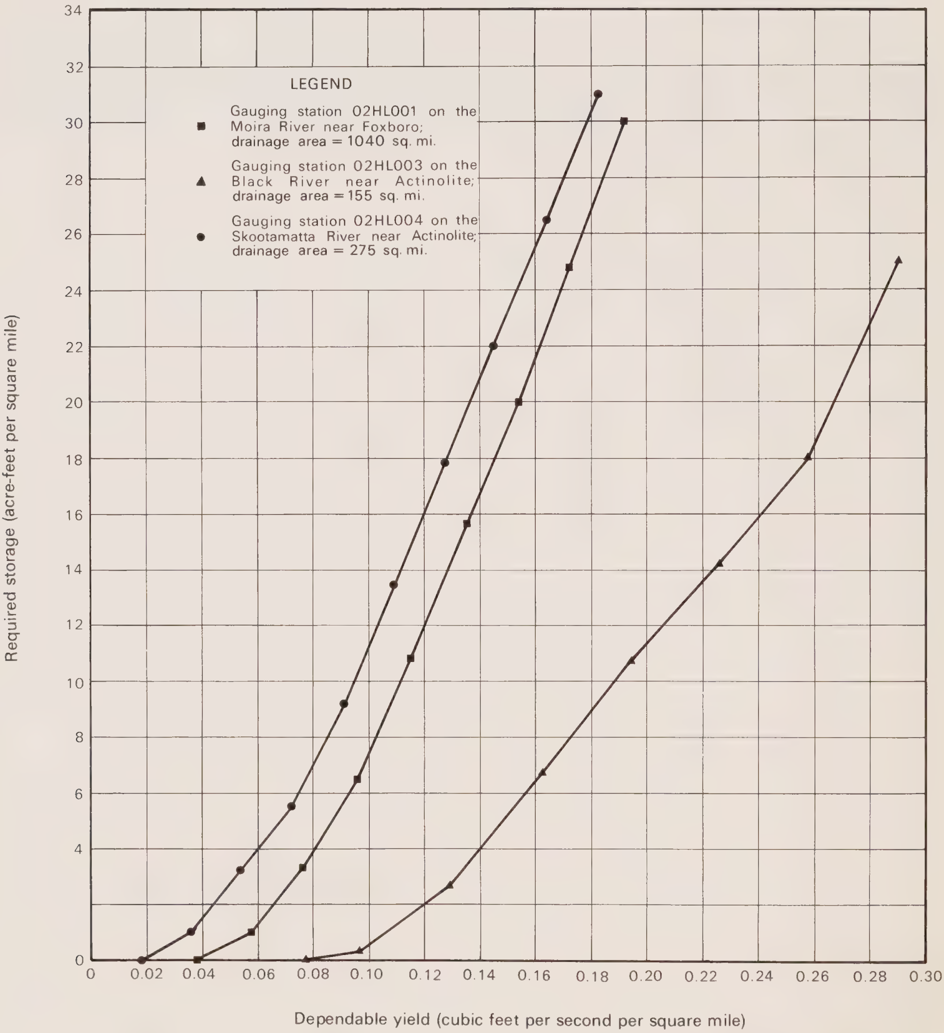


Figure 22. Curves relating required storage with dependable yields at gauging station 02HL001 on the Moira River near Foxboro, 02HL003 on the Black River, and 02HL004 on the Skootamatta River.

WATER LOSSES

Evapotranspiration

Evapotranspiration *(ET)* denotes water loss to the atmosphere by evaporation from free water surfaces, soil, snow, and ice, and transpiration by vegetation. The term describes the total water losses when it is impractical to estimate the separate losses by evaporation and transpiration. *ET* is an important parameter in the hydrologic budget because it accounts for a sizable loss of water from lakes and reservoirs, and from shallow ground-water storage. In many instances it may be the main process responsible for the decline of ground-water levels during the summer months.

Two empirical means of estimating *ET* in the Moira River basin have been used: one was developed by Thornthwaite as part of a total hydrologic budget calculation, and the other method was derived by Konstantinov. Climatic conditions at Tweed are considered to reflect average conditions in the basin and for this reason the temperature and precipitation data used to calculate *ET* by the Thornthwaite method were obtained from this station. However, since vapour pressures required for calculating *ET* by the Konstantinov method were not available at Tweed, these data were obtained from the Trenton meteorologic station. Hence, in comparing the *ET* results obtained by the two methods, differences may be due in part to climatic differences between Tweed and Trenton. Results obtained by the two methods vary significantly for some months of the 1970 water year, but it is difficult to determine which monthly values are more correct. The annual *ET* calculated by the Konstantinov method is judged to be a more realistic estimate and this method is subsequently used to estimate *ET* in five, annual, water-year hydrologic budgets.

Thornthwaite Method

An average *ET* for the 1970 water year was estimated by the Thornthwaite approach (Thornthwaite and Mather, 1955). The calculations were based on air temperature and precipitation at Tweed, and various stages in the calculation are shown in Table 6. Note that an estimate of the potential evapotranspiration *(PE)* is also made.

The Thornthwaite method of calculating *ET* is usually used as an approximation of annual *ET*. It is a relatively simple technique because it requires only air temperature and precipitation data. However, this method does not consider *ET* during months of sub-freezing temperatures, and this limitation is usually reflected in low annual values (Cruff and Thompson, 1967). The potential evapotranspiration for the 1970 water year was also estimated by this method and amounted to about 24 inches, which is approximately 11 per cent larger than the calculated *ET* during the year.

Konstantinov Method

The Konstantinov method was selected as an alternative to Thornthwaite's estimate as it does provide estimates of *ET* during periods of sub-freezing temperatures and it is easy to use

Table 6. Stages in the Thornthwaite Method for Calculating Potential and Actual Evapotranspiration for the 1970 Water Year
(Meteorologic data from Tweed station)

	1969			1970									Total
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
1. Air temperature (°F)	46.6	37.0	18.0	7.8	15.8	26.4	44.0	55.1	63.1	68.7	68.1	59.2	
2. Heat index	2.3	0.3	—	—	—	—	1.4	4.3	7.2	8.6	7.9	5.4	
3. Potential evapotranspiration *(PE)* (inches)	1.4	0.4	0	0	0	0	1.4	3.2	4.6	5.4	4.8	3.1	24.3
4. Precipitation (inches)	2.4	3.7	2.8	2.1	3.4	1.9	2.5	2.8	3.0	4.3	0.4	2.8	32.1
5. Precipitation minus potential evapotranspiration	1.0	3.3	2.8	2.1	3.4	1.9	1.1	−0.4	−1.6	−1.1	−4.4	−0.3	7.8
6. Continuous sum of the negative members of line 5								−0.4	−2.0	−3.1	−7.5	−7.8	
7. Total storage (inches)	7.2	10.5	13.4	15.5	18.9	20.8	11.8	11.5	10.2	9.3	6.4	6.2	
8. Changes in soil moisture (inches)	1.1	3.4	0	0	0	0	0	−0.3	−1.3	−0.9	−2.9	−0.2	
9. Actual evapotranspiration *(ET)* (inches)	1.4	0.4	0	0	0	0	1.4	3.1	4.2	5.3	3.2	3.0	22.1

Table 7. Data Used in the Calculation of, and the Actual Evapotranspiration by the Konstantinov Method for the 1970 Water Year

(Meteorologic data from Trenton station)

Month	Temperature (°F)	Vapour Pressure (millibars)	Evapotranspiration (inches)
1969 Oct	46.9	8.5	1.1
Nov	38.8	6.5	0.6
Dec	20.3	3.0	0.1
1970 Jan	11.8	2.3	0.0
Feb	19.6	3.3	0.4
Mar	27.8	4.1	1.2
Apr	43.8	6.6	2.0
May	54.6	10.5	3.4
Jun	63.5	14.3	3.9
Jul	69.2	19.0	4.9
Aug	67.2	16.4	4.0
Sept	60.8	14.6	1.4
Total			23.0

Table 8. Class A Pan Evaporation and Stoco Lake Evaporation during May to October 1970

Month	Evaporation (inches) Class A Pan	Stoco Lake	Pan Coefficient
May	4.3	3.3	0.77
Jun	6.3	4.9	0.78
Jul	6.1	4.9	0.80
Aug	5.9	4.5	0.77
Sep	3.4	2.6	0.75
Oct	1.8	1.4	0.74
Total	27.8	21.6	Average = 0.77

Annual lake evaporation = 25.7 inches, assuming May to October evaporation is 85% of the mean annual value (Bruce and Weisman, 1967, p. 20)

as only monthly mean air temperature and vapour pressure data are required (WMO, 1966; Szesztay, 1968).

Calculations of ET by this method utilize data from the Trenton meteorological station,. the closest station to the Moira River basin that provides vapour pressure data as part of its regular monitoring program.

Evapotranspiration for the 1970 water year was calculated to be approximately 23 inches (Table 7) with the highest loss occurring in July, and the lowest in January. During months of sub-freezing temperatures when the Thornthwaite method assumes ET to be zero, losses by the Konstantinov method totalled 1.7 inches. However, the annual estimates of ET differ by only 0.9 inches.

Annual evapotranspiration estimates obtained by this method were used in each of the annual water-year hydrologic budgets from 1966 to 1970 (Table 9). The average ET for the five budgets is 23.5 inches with the highest monthly estimates usually occurring in July or August, and the lowest in December or January.

Lake Evaporation

Many of the northern areas in the watershed are covered by open-water surfaces such as swamps, marshes, and lakes, and evaporation from these open bodies of water constitutes a significant loss of water from the basin. For example, in 1970 this loss was equivalent to a mean flow of approximately 100 cfs, or about 10 per cent of the annual mean flow of 1040 cfs out of the entire basin. This clearly indicates the need for determining lake evaporation in the watershed, and consequently evaporation estimates are presented in this report to provide such basic hydrologic data as may be required for reservoir design, and to supplement future water-budget studies in the area.

A variety of formulae are available for estimating lake evaporation (Christiansen, 1966; Chow, 1964; WMO, 1966), but many cannot be used because of the sophisticated data that are required for the calculations. In the present study, evaporation from Stoco Lake is calculated by converting Class A pan evaporation to lake evaporation as outlined by Kohler et al (1955). Pan evaporation data near Stoco Lake were gathered in the summers of 1969 and 1970 but only the data for 1970 is complete; consequently, the monthly lake evaporation estimates are presented only for the summer months of 1970 (Table 8). The equation on which the nomograms given in Kohler et al are based is:

$$E_L = 0.70 \ [E_p + 0.00051 p\gamma (0.37 + 0.0041\mu) (T_o - T_a)^{0.88}]$$

where E_L = lake evaporation
E_p = pan evaporation
p = atmospheric pressure
γ = proportion of advected energy to the pan which is used for evaporation
μ = wind speed
T_o = pan surface-water temperature
T_a = air temperature
0.70 = assumed pan coefficient

In reviewing the results shown in Table 8, some important points must be realized:

1. the empirical pan coefficient of 0.70 in the above equation is an annual average and is not necessarily indicative of individual monthly coefficients;
2. this method of conversion is applicable only to shallow lakes where changes in energy storage and advection can be ignored. Stoco Lake is considered to be shallow (maximum depth of 35 feet), but monthly changes in energy storage and advection may not be negligible throughout the year;

3. only six months of evaporation pan data are available. A twelve-month estimate of lake evaporation was obtained by multiplying the six-month value by a factor of 1.18 (Bruce and Weisman, 1967). This factor represents a mean value for the general area, established over several years.

The pan coefficient in this study ranged from 0.74 to 0.80, and the six-month average was 0.77. This average coefficient may be used in future approximations of E_L in the area by the equation:

$$E_L = 0.77\ E_P$$

It is interesting to note that the lake-evaporation estimate of 26 inches in 1970 agrees well with the estimate of 27 inches for the general area presented by Bruce and Weisman (1967) on their maps; an estimate of 30 inches of mean annual evaporation for the area is indicated by Ferguson et al (1970). As both the latter values represent long-term mean annual lake evaporation in the area, it is inferred that the lake evaporation during 1970 may have actually been below the long-term mean.

It is generally acknowledged that lake evaporation is a close approximation of potential evapotranspiration *(PE)*, and this is the basis for comparing evaporation from Stoco Lake to *PE* calculated by the Thornthwaite method as shown in Table 6. The Thornthwaite estimate of *PE* for the period of pan evaporation measurement is 24 inches, or about 8 per cent less than the lake-evaporation estimate. Similarly, in other situations where *PE* by the Thornthwaite method has been compared to lake evaporation, low values have been obtained by the investigators (Ferguson et al, 1970; Cruff and Thompson, 1967). This suggests that the Thornthwaite estimate of *PE* is low and it is suggested that the method not be used in areas where freezing temperatures are encountered or whenever enough meteorological data are available to calculate *PE* by other methods.

Using 26 inches of evaporation for lake surfaces, and an estimate of 53 square miles of open-water surface in the basin, the evaporation represents a decrease in streamflow out of the basin of approximately 100 cfs in 1970. This is a significant water loss in light of the mean annual flow of 1040 cfs at the Foxboro gauge.

Hydrologic Budget

The interrelationships among processes of the hydrologic budget can be stated mathematically by the following simplified water-balance equation:

$$P = R + ET \pm \Delta S$$

where P = precipitation
R = streamflow
ET = evapotranspiration
ΔS = changes in storage of ground water, surface water and soil moisture

Five annual budgets (Table 9) have been calculated to indicate the variability of the budget parameters during the 1966-1970 period, and to estimate an average annual budget for the basin during this interval. In each of the annual budgets, precipitation refers to measurements made at Tweed, runoff was measured at Foxboro, and *ET* was calculated by the Konstantinov method. Changes in storage have been included only to balance the equation and do not represent measurements in the field or calculations by any empirical method. In the average budget, a negative change in storage of 1.8 inches per year is required to balance the equation. In terms of streamflow, this is equivalent to approximately 140 cfs at the Foxboro gauge. It is doubtful, however, that surface- and ground-water storage have declined at this rate during the five-year period, and the apparent storage changes may be the result of cumulative errors in calculation of the other parameters.

Table 9. Five Water-Year Hydrologic Budgets for the Moira River Basin; 1966 to 1970 Water Years

Water Year	Precipitation (inches)	Runoff Direct (inches)	Runoff Ground Water (inches)	Runoff Ground Water as Percentage of Total Runoff	Evapo-transpiration (inches)	'Change in Storage' (inches)
1966	33.2	9.3	4.9	35	21.9	− 2.9
1967	39.4	9.7	4.9	34	23.3	+ 1.5
1968	39.0	11.0	4.2	28	24.0	− 0.2
1969	34.9	12.2	3.7	23	24.5	− 5.5
1970	32.2	7.7	2.5	25	23.8	− 1.8
Average	35.7	10.0	4.0	29	23.5	−1.8

HYDROCHEMISTRY

Introduction

Investigation of water quality in the basin dealt with sampling of stream, lake, and ground waters in the different geologic and geographic settings in an attempt to determine the total range of chemical water quality throughout the basin. This chapter deals only with the natural, uncontaminated surface- and ground-water quality. The quality of contaminated waters is discussed in the chapter on "Water Resources Problems and Management".

The initial sampling program was carried out during August 11 to 14, 1969, and was designed to determine only inorganic chemical water quality in the basin. A total of 124 samples were collected for routine chemical analysis; 29 from lakes, 28 samples from streams, 66 were taken from wells, and one sample was taken of rainwater (Figure 23). The results of these analyses are shown in tables 18, 19 and 20 in Appendix C. Table 20 also includes analyses for Tweed (2 samples), Madoc and Deloro municipal supplies, which were sampled by local municipal operators. Figures 30-35 (in Appendix C) indicate the locations and concentrations of the common chemical parameters used to classify the suitability of waters for domestic use—nitrate, total iron, total hardness, chloride, sulphate, and total dissolved solids. Values exceeding the permissible criteria are indicated.

The biological quality of stream and lake waters has been investigated by Owen and Galloway (1969) and reference should be made to this publication regarding discussions on the biological quality of surface waters. The effects of bacterial quality of water are noted in context of the suitability of water for domestic use.

The chemical quality of waters is discussed under three headings: stream water, lake water, and ground water, and ground-water quality is dealt with in terms of its occurrence in overburden, and in limestone, igneous, and metamorphic rock environments. Only a brief comment is made regarding ground-water quality in overburden because water supplies in the basin are obtained mainly from bedrock wells. Only two samples were taken from overburden wells.

Surface Water

A total of 28 water samples were taken from nine lakes in the basin, and one sample was obtained from the Bay of Quinte (L. Ontario) at Belleville. Some lakes were sampled at more than one location, as well as at various depths at any one sampling site. The sampling locations are shown on Figure 23 and the results of the analyses are listed in Table 18 in Appendix C.

Twenty-eight water samples were collected from 11 streams in the basin. The locations of the sampling points are shown on Figure 23 and the results are tabulated in Table 19 in Appendix C.

In general, the chemical quality of water in streams is similar to water quality in the lakes, and the best stream-water quality occurs in the Skootamatta and Black rivers, and presumably in their tributaries. In most instances though, water in streams has a slightly higher total dissolved solids content than water in the lakes.

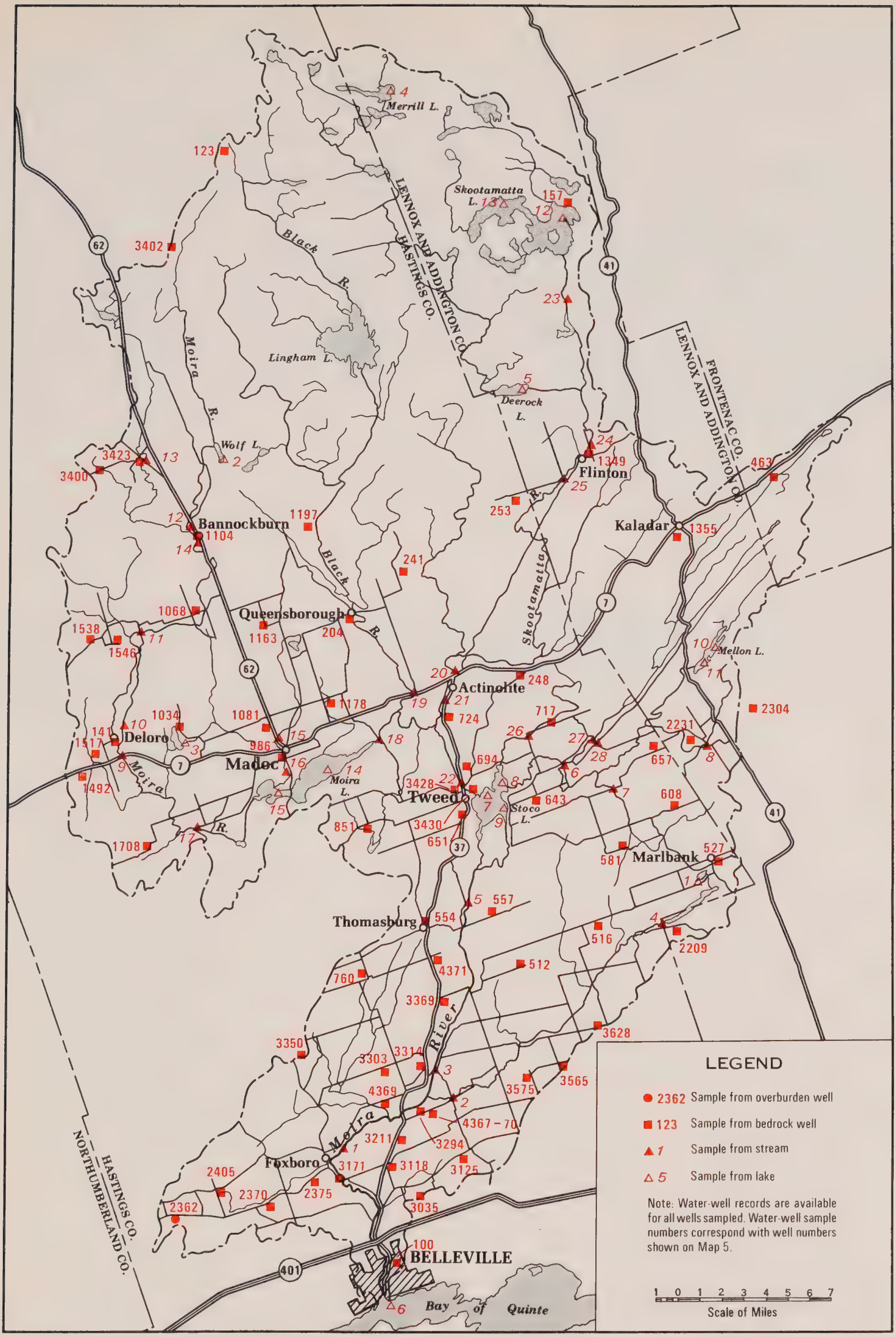


Figure 23. Locations of water quality sampling sites.

Lake Water

Generally there were insignificant variations in the chemical quality of water within any one lake, and consequently, analysis of only one sample from each lake is used to illustrate its chemical quality, as shown in Table 10.

Lake-water quality can be categorized into two groups on the basis of water chemistry. There are four lakes in the first group: Merrill, Skootamatta, Deerock, and Mellon. The chemical composition of waters in these lakes displays chemical characteristics similar to that of local rainwater; very low total dissolved solids *(TDS)*, and correspondingly low ionic concentrations (Table 10). In most instances, the lake waters are very soft and pH values are usually less than 7.0. Three of the lakes—Merrill, Skootamatta, and Deerock—are located in the Skootamatta River sub-basin and analyses from these lakes are indicative of lake-water quality in virtually uninhabited areas on granitic terrain. The fourth lake, Mellon, is in the Clare River sub-basin and is also situated in a granitic environment.

Lingham Lake, in the Black River sub-basin, although not sampled, is considered to have similar water quality because it occurs in the same area as the other four lakes.

Table 10. Minimum, Maximum, and Mean Concentrations of Common Chemical Constituents in Lakes, Streams, and Rainwater in the Moira River Basin
(Sampled in August 1969)

		Chemical Constituent (ppm)								
		Na	Ca	Mg	HCO_3	SO_4	Cl	Hardness	TDS	pH
Lake Waters (one sample per lake)										
Group 1	Min	1	5	1	12	11	1	21	40	6.0
(4 samples)	Max	3	10	1	28	14	2	30	45	7.5
	Mean	1	7	1	18	13	1	25	40	6.8
Group 2	Min	1	22	2	67	9	1	62	120	7.5
(6 samples)	Max	4	55	5	169	18	6	159	210	8.5
	Mean	3	42	4	127	15	3	120	167	7.9
Stream Waters										
Group 1	Min	1	6	1	17	9	1	24	30	7.1
(7 samples)	Max	2	15	7	54	13	3	52	90	7.7
	Mean	1	10	3	34	11	2	37	55	7.3
Group 2	Min	1	34	3	94	7	1	98	120	7.1
(21 samples)	Max	14	86	19	322	38	11	288	330	8.4
	Mean	5	52	7	171	19	5	106	200	7.9
Rainwater										
(1 sample)		0.4	4	1	15	6	1	13	28	7.5

There are five lakes in the second group: Wolf, Jarvis, Moira, Stoco, and Dry. The single water sample from the Bay of Quinte is also in this group. Water quality in these lakes is distinguished from that in the first group by appreciably higher *TDS*, higher hardness values, and pH always exceeds 7.0. Higher concentrations of chemical constituents in these lakes may be due, in part, to more abundant soluble minerals in the metamorphic and carbonate rock environments in which these lakes are located. These rock types are generally more susceptible to weathering, and the minerals they contain are more soluble. Moira, Jarvis, and

Wolf lakes are located in the upper Moira River watershed and receive runoff from metamorphic rock areas. Dry Lake is underlain by limestone, and Stoco Lake, although itself situated in granite, receives runoff from several different Precambrian rock environments other than granite.

All lake waters have a predominance of Ca^{++} and HCO_3^- and display relatively small variations in concentrations of the major ions.

The chemical quality of water from lakes is generally suitable for most uses, including domestic use, but data on file with the Ministry indicate that the bacterial quality of some lake waters, notably in Moira and Stoco lakes, render the waters unfit for human consumption at certain times of the year (Owen and Galloway, 1969). In all instances where lake water is to be used for drinking and/or bathing it is advisable to first determine its bacterial quality. As in some stream-water samples, water samples from Moira and Stoco lakes contained undesirable amounts of arsenic. This problem has been investigated by Owen and Galloway (1969) and their findings are described briefly in the "Water Resources Problems and Management" chapter.

Stream Water

Two different types of stream-water quality are evident. Seven samples of waters in the Black and Skootamatta rivers, and in a tributary of Otter Creek, constitute the first group and are characterized by low *TDS,* low hardness, and generally low ion concentrations. Samples in the second group include those from the remaining eight streams sampled (Parks, Moira, Clare, Goose, Jordan, Madoc, Sulphide and Otter), in which the concentrations of almost all the chemical parameters are higher than in waters in the first group (Table 10).

In both groups Na^+ and Mg^{++} concentrations are usually small and Ca^{++} is the predominant cation. Of the anions, HCO_3^- concentrations substantially exceed both SO_4^{--} and Cl^- concentrations. Because of the predominance of Ca^{++} and HCO_3^-, stream waters are classed as 'calcium-bicarbonate' type.

The highest Ca^{++} and HCO_3^- concentrations were found in samples taken from two locations on Madoc Creek and in one sample from Goose Creek. The water in Madoc Creek, however, is thought to be polluted to some degree by waste effluent discharges from Madoc, and therefore does not indicate natural water quality in the stream. Goose Creek, on the other hand, is pollution-free and indicates natural stream-water quality in a small watershed located in a predominantly limestone plain area of the basin. In Parks Creek, also located in this limestone plain, Ca^{++} and HCO_3^- concentrations are also high.

It is interesting to note the increase in total dissolved solids in the downstream direction in the Skootamatta River (Figure 35) which drains an area underlain primarily by granitic bedrock. The *TDS* in waters sampled at four successive downstream sampling points increased from 35 ppm at a point just south of Skootamatta Lake, to 90 ppm near the mouth of the river about ¾ miles downstream of Actinolite. The largest increase, from 50 to 90 ppm, occurred as the river flowed through Actinolite. No obvious reason for this increase could be found. Even though the increase in dissolved solids in the river between Skootamatta Lake and Actinolite was almost threefold, the *TDS* of 90 ppm indicates a relatively small dissolved mineral content. In fact, the stream water from Skootamatta River, together with water from the Black River, dilutes the *TDS* in the Moira River from 190 ppm as the water flows out of Moira Lake, to 120 ppm just north of Tweed.

At most locations in the basin, stream water is of acceptable chemical quality for a variety of uses, of which domestic and recreation uses are the most important. In many instances, however, the bacterial quality is poor, and in assessing the suitability of stream water for domestic use, especially for drinking purposes, bacterial quality should be determined in conjunction with chemical quality.

Ground Water

The chemical quality of ground water is discussed according to its occurrence: 1) in overburden, 2) in limestone, 3) in igneous rock, and 4) in metamorphic rock. The analyses are tabulated in Table 20 in Appendix C, and the hydrogeologic data for the sampled wells are listed in Table 17 in Appendix B. In each environment the water quality appears to be distinctly different from ground-water quality in the other geologic settings (Table 11). Generally, the least mineralized ground water occurs in igneous rock areas in the northern parts of the watershed, and the most highly mineralized waters are found in deep limestone wells mainly in the extreme southern portions of the basin. Water from overburden wells is generally of better quality than that obtained from limestone and metamorphic rocks. It contains higher dissolved solids than waters in igneous rocks.

Table 11. Minimum, Maximum, and Mean Concentrations of Common Chemical Constituents in Ground Waters in Overburden, Limestone, Igneous and Metamorphic Rock Areas in the Moira River Basin
(Sampled in August 1969)

		Chemical Constituent (ppm)							
		Na+K	Ca	Mg	HCO_3	SO_4	Cl	Hardness	TDS
Wells in Overburden									
(2 samples)	Mean	6.6	72	18	289	13	3	252	275
Wells in Limestone (calcium-bicarbonate type waters)									
	Min	3.0	84	2	254	18	2	231	260
(15 samples)	Max	114	158	35	380	149	139	440	880
	Mean	30.6	108	17	331	51	41	339	500
Wells in Limestone (calcium-sulphate and sodium-chloride type waters)									
	Min	16.2	45	17	236	116	4	181	800
(4 samples)	Max	569.9	324	53	341	540	1233	1030	3050
	Mean	213	208	32	293	332	362	653	1470
Wells in Igneous Rock									
	Min	3.0	16	4	39	14	2	56	100
(9 samples)	Max	27.2	93	14	299	50	13	286	340
	Mean	10.5	55	7	177	29	6	168	214
Wells in Metamorphic Rock									
	Min	8.9	48	6	215	8	8	143	300
(7 samples)	Max	55.8	123	25	433	47	42	398	550
	Mean	27.6	90	14	313	35	19	284	385

In Overburden

Only a small percentage of wells in the basin derive water from overburden aquifers, and for this reason only two overburden wells were sampled. Both of these wells are in the southwestern part of the basin where overburden wells are most common.

The waters in both wells are of calcium-bicarbonate type and contain only a small amount of dissolved minerals. Analyses of both samples indicate the waters to be suitable for domestic use with only iron exceeding its recommended limit; however, the waters are very hard (Table 20 in Appendix C, and figures 30-35).

In Limestone

Ground water in limestone regions of the basin generally contain larger amounts of dissolved minerals than waters in granitic and metamorphic regions. At some locations in the southern parts of the watershed, water from deep limestone wells is so highly mineralized that it is not suitable for domestic use. Ions such as Na^+, K^+, SO_4^{--} and Cl^-, which usually occur in small concentrations in most uncontaminated ground waters in the basin, are high in a number of wells in limestone.

Fifteen of the 19 samples that are used to indicate natural quality of water in limestones are of the 'calcium-bicarbonate' type, i.e., Ca^{++} and HCO_3 are the dominant ions. The chemistry of these waters will be discussed separately from the remaining four samples, of which two are 'calcium-sulphate' type and two are 'sodium-chloride' type.

Calcium-Bicarbonate Type Waters

The calcium-bicarbonate type of ground water is common in wells obtaining water from limestone. Within this category, however, there are large variations in chemistry among individual water samples. The largest variations in ion concentrations occur among $Na^+ + K^+$, and Cl^- ions (Figure 24); Na^+ concentrations are usually considerably higher than K^+. Generally, the concentrations of these three ions in water can be expected to increase with depth, and deep wells in the southern parts of the basin commonly yield waters containing high $Na^+ + K^+$ and Cl^- concentrations.

The smallest variations occur among Ca^{++} and HCO_3^- ions, which are consistently higher than any of the other ions, and they usually contribute 60 per cent or more to the total dissolved solids. Thirteen of the 15 samples have *TDS* less than 600 ppm, and one sample has *TDS* less than 300 ppm. The mean *TDS* is 500 ppm, which corresponds to the permissible criteria for drinking water.

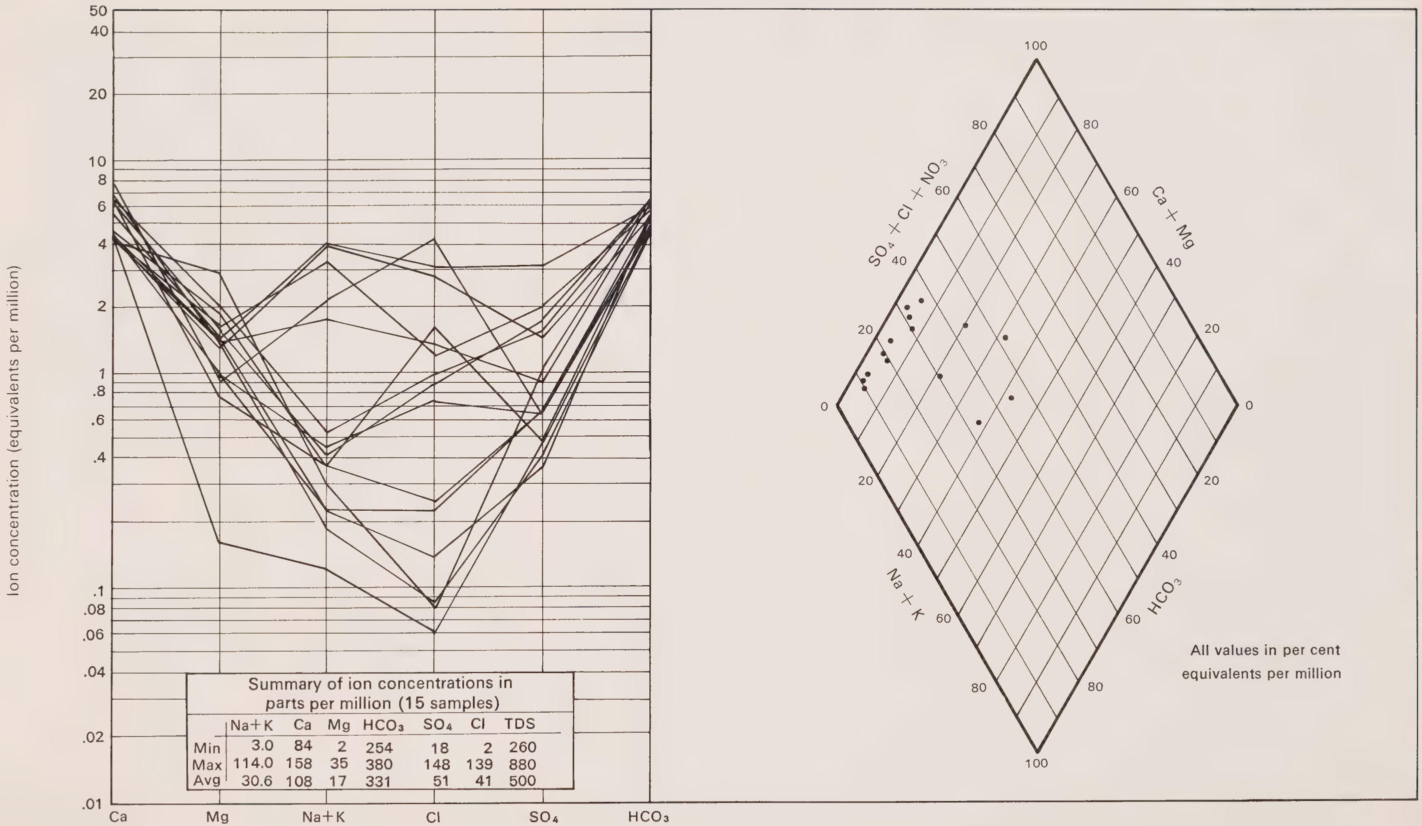
Most of the calcium-bicarbonate type waters in limestone are suitable for domestic use. However, the waters are very hard and softening is advisable in some circumstances. Although *TDS* slightly exceed 500 ppm in eight of the samples, none of the other chemical parameters exceed the recommended limits. (Figures 30-35 in Appendix C).

Calcium-Sulphate and Sodium-Chloride Type Waters

Two ground-water samples were of the calcium-sulphate type, and two were of the sodium-chloride type. These four non-carbonate waters are the most highly mineralized waters in the basin, and the large concentrations of Na^+, SO_4^{--}, and Cl^- (Figure 25) make these waters undesirable for human consumption. In two of the wells the driller reported the water to be "salty" but in the other two the waters were classified "fresh" at the time of drilling.

The differences in water quality between these 4 samples and the 15 calcium-bicarbonate samples from limestone wells are pronounced. The average $Na^+ + K^+$ concentration for the four samples is approximately seven times greater than for the calcium-bicarbonate type waters; SO_4^{++} concentrations are approximately six times greater, and Cl^- concentrations are about nine times greater. The mean *TDS* for the four samples is 1470 ppm, compared to a mean of 500 ppm for the other limestone waters. There is no correlation of these highly mineralized waters with specific limestone areas, as the four wells are located randomly throughout the limestone areas of the basin; nor is there an apparent correlation of hydrochemistry with well depths which range from 45 to 148 feet for the four wells.

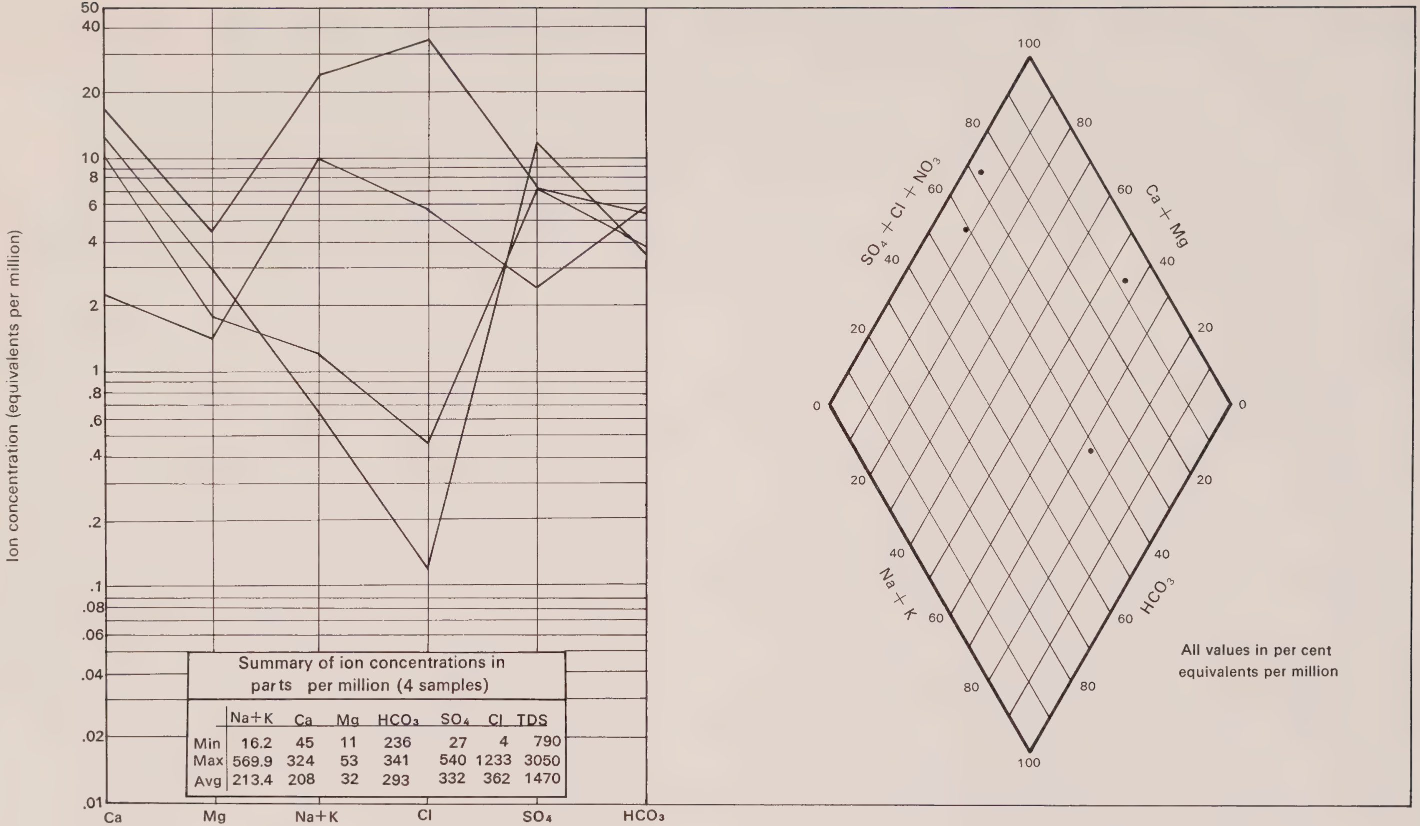
In addition to sampling domestic wells, water samples were taken from four small diameter wells (4367, 4369, 4370, 4371) drilled during the field work in 1969. Analyses of these samples, listed in Table 20 in Appendix C, indicate the presence of sodium-chloride waters at



Summary of ion concentrations in parts per million (15 samples)

	Na+K	Ca	Mg	HCO_3	SO_4	Cl	TDS
Min	3.0	84	2	254	18	2	260
Max	114.0	158	35	380	148	139	880
Avg	30.6	108	17	331	51	41	500

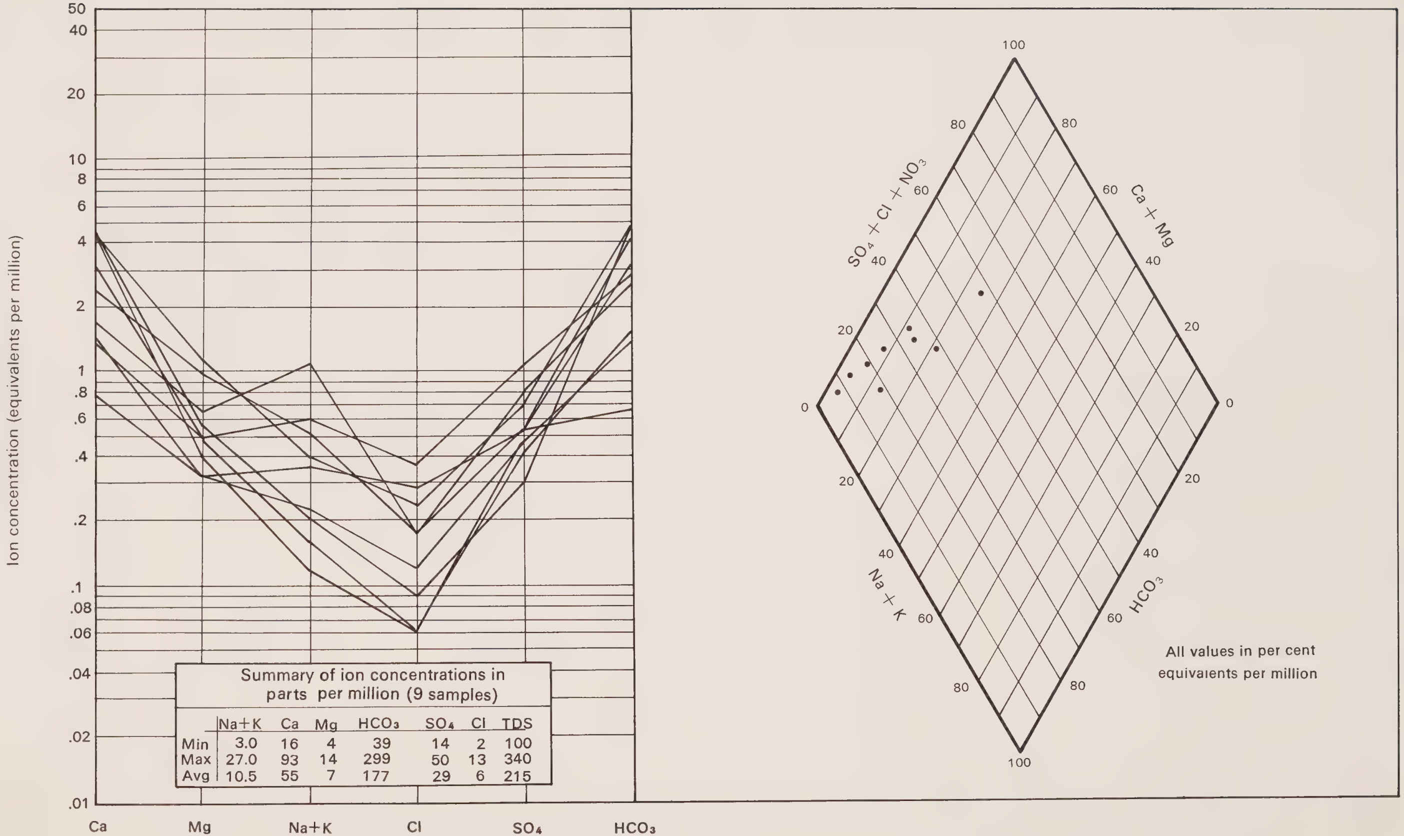
Figure 24. Major-ion chemistry of ground water in Palaeozoic limestone; calcium-bicarbonate type waters.



Summary of ion concentrations in parts per million (4 samples)

	Na+K	Ca	Mg	HCO_3	SO_4	Cl	TDS
Min	16.2	45	11	236	27	4	790
Max	569.9	324	53	341	540	1233	3050
Avg	213.4	208	32	293	332	362	1470

Figure 25. Major-ion chemistry of ground water in Palaeozoic limestone; sodium-chloride and calcium-sulphate type waters.



Summary of ion concentrations in parts per million (9 samples)

	Na+K	Ca	Mg	HCO_3	SO_4	Cl	TDS
Min	3.0	16	4	39	14	2	100
Max	27.0	93	14	299	50	13	340
Avg	10.5	55	7	177	29	6	215

Figure 26. Major-ion chemistry of ground water in Precambrian igneous rocks.

a depth of 55 feet near Thomasburg, as well as potassium-chloride waters from a depth of 165 feet at the same site. Analyses of samples from deep piezometers located on either side of the Moira River northeast of Foxboro also indicate sodium-chloride water at depth. Most sodium-chloride type waters in the basin contain chloride concentrations in excess of the recommended limit of 250 ppm, and waters from the piezometers contain such a high concentration of Cl^- (up to 19,460 ppm) that the water is unpalatable.

The calcium-sulphate type waters are similarly not recommended for consumption as the criteria of 250 ppm for SO_4^{--} is exceeded in all waters of this type.

In Igneous Rock

Igneous rocks are composed predominantly of silicate minerals, which are relatively resistant to chemical and mechanical weathering. Consequently, ground water in these rocks contains relatively low concentrations of dissolved minerals. Ground water in granitic areas is the 'purest' ground water in the basin, i.e., it contains the least amount of dissolved solids. The total dissolved solids content in eight of the nine samples was less than 300 ppm, and the mean for the nine samples was 214 ppm (Table 11). By contrast, this is almost 50 per cent less than the mean *TDS* for ground water in metamorphic rocks, and only about 15 per cent of the average *TDS* concentration of the most mineralized waters that occur in the limestones.

Figure 26 indicates that Ca^{++} and HCO_3 are the dominant ions in all nine samples, and that Mg^{++} and Cl^- concentrations are the smallest. The concentrations of all ions are less than in ground waters from metamorphic and limestone rocks.

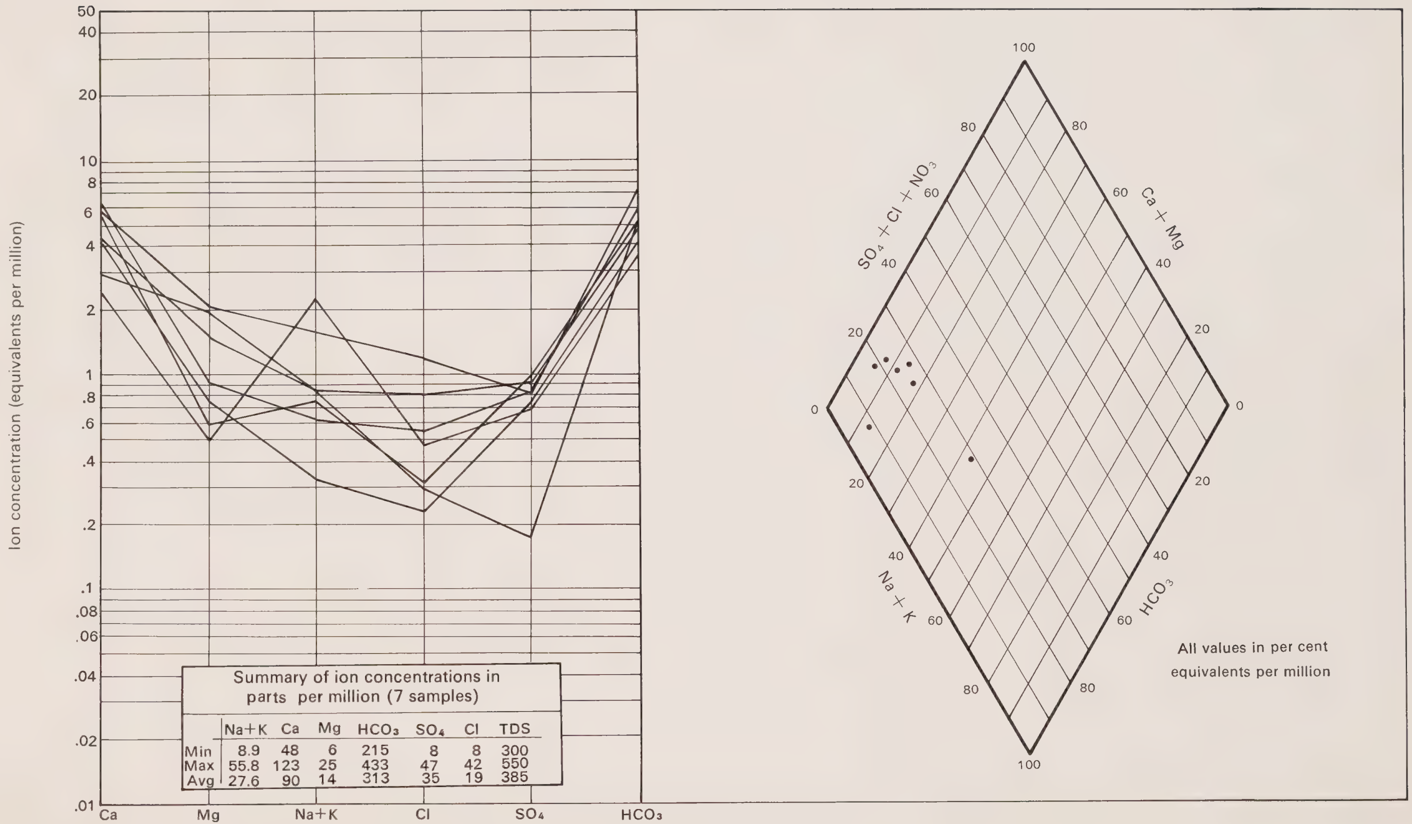
The concentration of chemical constituents in all sampled waters were lower than the permissible criteria for drinking water, but in about half of the samples the water is very hard (figures 30-35 in Appendix C).

In Metamorphic Rock

The natural chemical quality of ground water in metamorphic rock regions of the basin is good. The largest area of outcrop of metamorphic rocks occurs in the northwestern part of the basin, and six of the seven samples used to indicate natural quality were obtained from this region. The seventh sample was taken from a well located in metasedimentary rocks east of Actinolite, and its hydrochemistry is considered to represent ground-water quality in metamorphic rocks in the vicinity of Otter Creek. Five other ground-water samples taken from metasedimentary rock regions throughout the basin contained suspected chloride and/or nitrate contamination and are not included in this discussion.

The total dissolved solids content of waters in metamorphic rocks is considerably higher than in ground-water samples in igneous rocks, but less than in samples obtained from wells in limestone. The mean *TDS* for the seven samples is 385 ppm, with HCO_3^- and Ca^{++} the predominant ions (Table 11). The *TDS* concentrations vary from location to location and no distinctions can be made between *TDS* in waters in metavolcanic and in metasedimentary rock areas. Except for one analysis, *TDS* in all samples were less than 500 ppm. As with water samples from granitic environments, the ionic concentrations of the major cations and anions are low, with Ca^{++} and HCO_3^- the highest (Figure 27).

On the basis of inorganic chemical quality, ground water in metamorphic rocks is generally suitable for domestic use, although on occasion the *TDS* exceeds the recommended limit of 500 ppm for drinking water (see figures 30-35 in Appendix C). This excess is only slight and does not prevent the water from being used as a domestic supply. However, the water is usually very hard; the average for the seven samples is 284 ppm, and in some samples the total iron concentration also exceeds the criterion of 0.3 ppm. These excesses are not serious and do not restrict the use of water for domestic purposes.



Summary of ion concentrations in parts per million (7 samples)

	Na+K	Ca	Mg	HCO_3	SO_4	Cl	TDS
Min	8.9	48	6	215	8	8	300
Max	55.8	123	25	433	47	42	550
Avg	27.6	90	14	313	35	19	385

Figure 27. Major-ion chemistry of ground water in Precambrian metamorphic rocks.

PRESENT WATER USE

Introduction

The main water uses in the basin are categorized and discussed under the following headings: municipal, rural domestic, industrial, agricultural, waste assimilation and recreation. The locations of major water uses are shown in Figure 28 and a listing of the major dams and their intended uses are indicated in Table 12.

Municipal Use

Four municipalities have communal water-supply systems: Belleville, Tweed, Madoc and Deloro (Table 13) and of these, Belleville's system is the largest as it served more than 35,000 people in 1974. The smallest system, in Deloro, supplied only 215 residents. All systems serve industrial and commercial enterprises, but private households are the main users.

Belleville's water supply is obtained from the Bay of Quinte and prior to distribution it is treated mechanically by screening, micro-straining and filtering. Its chemical treatment includes chlorination and the addition of alum and hydrofluorosilicic acid. The system has been capable of satisfying the city's average daily needs of 5.0 mgd, but not the present estimated maximum-day demand of 12.5 mgd. Consequently, an expansion of the system is anticipated.

Table 13. Municipal Water Supply Systems, Moira River Basin, 1974

Municipality	Source of Supply	System Capacity (mgd)	Consumption (mgd)			Average per Capita Consumption (gpd)
			Maximum Day	Maximum Month	Average Day	
1. Belleville	Surface water (Bay of Quinte)	12.00	12.5*	7.86	5.0	150
2. Tweed	Ground water (2 wells)	0.44	0.24	0.18	0.15	83
3. Madoc	Ground water (2 wells)	0.33	0.30	0.25	0.18	190
4. Deloro	Ground Water (1 well)	0.36	0.53*	0.03**	0.02***	100
Total		13.13	13.57	8.32	5.35	

* Maximum day consumption is calculated by multiplying the average day value by 2.5

** Maximum month consumption is calculated by multiplying the average day value by 1.5

*** Average day consumption for Deloro is calculated by multiplying the population served (215 in 1974) by 100 gallons per day.

Table 12. Dams and Their Uses, Moira River Basin, 1970

Watershed	Dam*	Use	Remarks
Moira River	M-1	Recreation and conservation	Operated by the Moira River Conservation Authority; reservoir capacity is 98 acre-feet; the reservoir previously provided a water reserve for the Deloro Smelting and Refining Company
	M-2	Recreation and flood control	Controls outlet of Moira Lake; operated by the Moira River Conservation Authority
	M-3	Recreation and flood control	Controls outlet of Stoco Lake, together with M-4; operated by the Moira River Conservation Authority
	M-4	Recreation and flood control	Controls outlet of Stoco Lake, together with M-3; operated by the Moira River Conservation Authority
	M-5	Mill operation	
	M-6	Abandoned	Previously used for mill operation
	M-7	Storage for Corby's Distillery Limited	
	M-8	Recreation	Operated by the Moira River Conservation Authority; previously used for mill operation
	M-9	Abandoned	Previously used for mill operation
	M-10	Recreation	Operated by the Moira River Conservation Authority; previously used for mill operation
Black River	B-1	Streamflow augmentation	Controls outlet of Lingham Lake; operated by the Moira River Conservation Authority; reservoir capacity is 27,900 acre-feet; usable capacity is 14,000 acre-feet
	B-2	Recreation	
	B-3	Recreation	
Skootamatta River	S-1	Recreation and streamflow augmentation	Controls outlet of Skootamatta Lake; operated by the Ontario Ministry of Natural Resources; maximum draft is 9¾ feet. Previously used for mill operation
	S-2	Abandoned	Previously used for mill operation
	S-3	Abandoned	Previously used for mill operation
	S-4	Abandoned	Previously used for mill operation
	S-5	Recreation	
	S-6	Recreation, streamflow augmentation, and flood control	Controls outlet of Deerock Lake; operated by the Moira River Conservation Authority; reservoir capacity is 7,500 acre-feet
Parks Creek	P-1	Recreation and conservation	Operated by the Moira River Conservation Authority

* Location shown on Figure 28

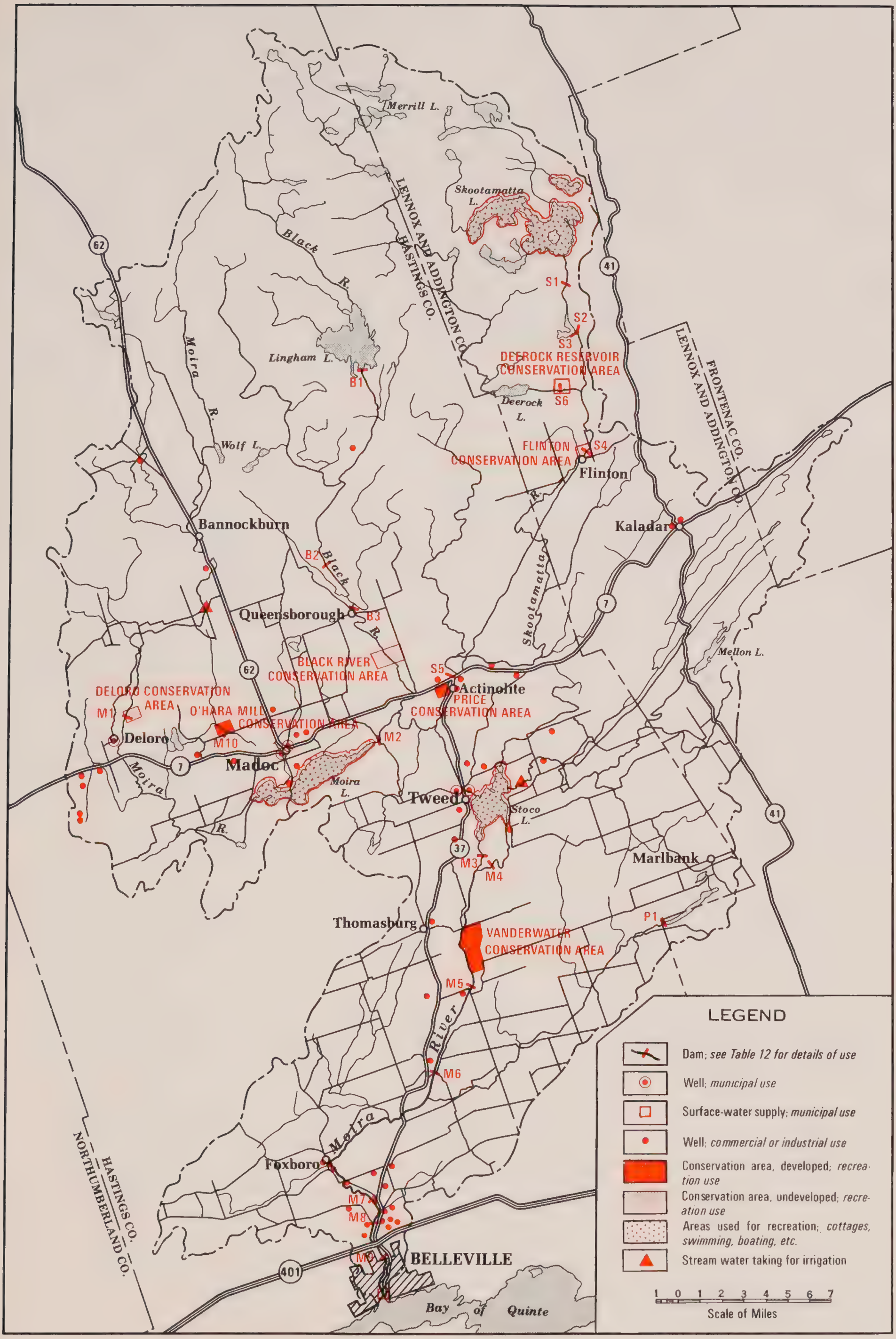


Figure 28. Water use in the Moira River basin, 1970.

Tweed obtains its water supply from two deep wells (435 feet and 351 feet) in granite. Water from one of the wells is chlorinated, while water from the other well is untreated. The system served about 1815 people in 1974, with an average per capita consumption during this time, including industrial and commercial uses, of about 83 gpd. The estimated maximum-day demand of 0.24 mgd is considerably less than the capacity of the system of 0.44 mgd, and the average daily consumption of 0.15 mgd is approximately one-third of the system's capacity. No expansion of the system is planned in the near future.

Two deep wells, one 160 feet deep and the other 189 feet deep in rock, provide water for the Madoc municipal system. The system's capacity of 0.33 mgd is sufficient to satisfy the estimated maximum-day demand of 0.30 mgd and is considerably in excess of the average day consumption of 0.18 mgd in 1974. Problems associated with gasoline pollution and interference caused by the second municipal well, which was drilled in 1971, have put a strain on the total system and future modifications are anticipated.

The Deloro system consists of one well 70 feet deep in granite. The supply is chlorinated prior to distribution. The present capacity of 0.36 mgd appears to be sufficient to meet future demand in the village, although the estimated maximum day exceeds the system's capacity.

Rural Domestic Use

Population, and hence water use, is most intensive in the southern parts of the basin where water supplies are developed mainly through wells in limestone.

The rural population in the basin not served by municipal water-supply systems was estimated to be 14,000 in 1974. The quantity of water used for rural domestic purposes is taken to average about 75 gallons per day (gpd) per capita, and using this consumption, the rural water use in the basin is approximately 1,050,000 gpd. Most of this need is supplied by ground water, with only a very small percentage obtained from surface-water sources.

Water use in the northern sections of the basin is small because rural settlement is sparse and generally restricted to hamlets along main highways. Most domestic water supplies are obtained from rock wells that supply adequate amounts of water for domestic use, but in some areas along Highway 62 north of Madoc, only marginal quantities of ground water are available for domestic use.

Industrial Use

A large number of industries in the basin are not served by municipal water-supply systems, and most of them obtain their supplies from individual wells. However, the quantity of water used by the different industrial concerns varies widely and has not been inventoried for this report.

One of the largest industrial users in the basin is Corby's Distillery Limited in Corbyville. Part of its water supply is obtained from ground-water sources. During the summer, the plant also takes an estimated average of 1.2 million gallons of water per day from the Moira River adjacent to its plant. Occasionally during periods of low flow in the summer, water shortages have occured.

Manufacturing industries that depend heavily on adequate water supplies include several cheese factories and a number of gravel pits and stone quarries located in the southern part of the basin. A gravel pit operated by the Triangle Paving Company near Foxboro requires about 300 gpm of water during peak production. It obtains this water from a large pit at the site.

There are several mines in the watershed, the largest being the iron ore mine south of Marmora, which is owned by the Marmora Mining Company Limited. The amount of water used by the mining industry is probably small because most mining operations in the basin are reported to be dry.

Agricultural Use

The amount of water used for agriculture is estimated to be small since only two permits to take water for this purpose existed in 1974. One permit allows the taking of 48,000 gpd from the Moira River near Eldorado to irrigate pasture land, and the other allows extraction of 600,000 gpd from the Clare River near Sulphide to irrigate potato and farm crops (Figure 28).

The amount of water used by livestock was estimated to be 676,000 gpd, of which 95 per cent is required for dairy and beef cattle (Table 14).

Table 14. Estimated Water Requirements for Livestock in the Moira River Basin

Animal	Number*	Water Required** (gpd)
Dairy cattle	7,000	350,000
Beef cattle	24,000	288,000
Swine	14,000	21,000
Horses	800	10,000
Poultry	75,000	4,000
Sheep	2,000	3,000
Total		676,000

* Based on 1966 data (Ont. Dept. Ec. and Devt., 1968)

** Calculated from average daily requirements per animal as outlined by Hore (?)

Waste Assimilation

As of 1974, sewage and waste-water effluent was discharged by four municipalities and one industrial system. Municipal systems are located in Belleville, Tweed, Madoc and Deloro (Table 15); the largest is in Belleville and the smallest in Deloro. Corby's Distillery Limited owns the largest private plant in the basin.

Belleville's treatment plant, with a capacity of 8.00 mgd, provides secondary treatment and discharges an average of 6.9 mgd of effluent into the Bay of Quinte.

Sewage discharges from Tweed's treatment system have had adverse effects on water quality in the Moira River and Stoco Lake in the past, and a Ministry-operated 2-cell, 24-acre lagoon and sanitary sewers are under construction. The estimated completion date for this construction is December 1975.

Sewage effluent from Madoc has often resulted in coliform contamination and destruction of aquatic life in Deer Creek (also known as Madoc Creek), but has not affected water in Moira Lake significantly. Assuming sewage effluent to be equal to average water use, an average effluent discharge of 0.36 cfs (1974) is estimated to be discharged into Deer Creek. This is often equal to the natural streamflow in the creek during the summer. At present, Madoc's plant consists of 2 equal cell lagoons, each cell being 15 acres in size.

The Deloro sewage treatment consists of a communal septic tank and an underdrain tile bed system. The effluent from this plant is generally of poor quality, but improves as it trickles through a swamp prior to discharging into the Moira River. Chlorination of Deloro's effluent has been recommended by the Ministry of the Environment.

Corby's Distillery Limited has three waste treatment systems, one for its sanitary waste, and two for industrial waste. The sanitary waste treatment consists of a lagoon which handles up to 6000 gallons of sewage per day, and effluent from it has caused localized pollution during low flows in the Moira River below the outfall at Corbyville. The Ministry has suggested

to the company the replacement of the present continuous discharge system by one that discharges only in the spring and fall, and an expansion of the single lagoon is also under consideration. One of the two industrial waste-treatment systems reduces the organic loading of the industrial sewage and the quality of the effluent from this system has been satisfactory. The other industrial waste system consists of a cooling tower to lower the temperature of uncontaminated water from the company's ventilation system prior to being discharged into the Moira River.

Table 15. Sewage Treatment Plants, Moira River Basin, 1974

Sewage Treatment Plant	Design Capacity (mgd)	Average Daily Flow (mgd)	Type of Treatment	Receiving Body of Water	Remarks
Belleville	8.00	6.9	Secondary; activated sludge	Bay of Quinte (Lake Ontario)	Present sewage treatment is satisfactory; prior to mid-1971, treatment for Belleville's effluent was primary only
Tweed	0.177	Not metered, 1800 people served	Three large septic tanks	Two outfalls to the Moira River and one to Stoco Lake	A Ministry operated 2 cell, 24-acre lagoons and sanitary sewers are under construction; completion scheduled for Dec. 1975
Madoc	0.36	Not metered, 899 people served	Lagoons	Deer Creek just above Moira Lake	There has been a high rate of infiltration of ground water into the sewer system; steps are being taken to reduce this infiltration
Deloro	0.08	Not metered, 200 people served	A septic tank and underdrain tile bed system	Moira River	A poor quality effluent is discharged from this system into a swamp which drains into the Moira River; further refinement of the effluent is received as the effluent trickles through the swamp; chlorination of the effluent has been recommended by the Ministry of the Environment
Corby's Distillery Limited					
1) Sanitary sewage	unknown	Not metered, estimated to be 3500 to 6000 gpd	A ⅞-acre lagoon	Moira River	Recommendations for upgrading certain aspects of this system have been presented to the company by the Ministry of the Environment
2) Industrial sewage	0.30	0.22	Secondary; activated sludge	Moira River	Quality of effluent is satisfactory; maximum daily flow through this plant is 0.29 mgd
3) Industrial cooling	1.68	1.30	'Cooling tower'	Moira River	The cooling tower was constructed to reduce the temperature of uncontaminated cooling water to below 85°F before it is discharged into the river during summer months

Recreation

Recreation is a major use of water in the basin during the summer months, with activities such as swimming, boating, and fishing being the main water-based activities.

Nearly all lakes are developed to accommodate vacationers and tourists, but most developments are concentrated on the Moira, Stoco, and Skootamatta lakes. Although most of the lakefront is privately owned and developed for private use only, a few acres are commercial and open to the public. Several tourist camps, used primarily for fishing, are located on Moira, Stoco, and Skootamatta lakes. There is a private camp on the south side of Moira Lake (Quin Mo Lac), and swimming, boating, and fishing are major activities available at this camp.

Public recreation facilities in the basin are provided in conservation areas and municipal parks. The Moira River Conservation Authority operates seven park areas in the basin (Figure 28). However, only three of these have been developed: Colonel Roscoe Vanderwater Conservation Area, O'Hara Mill Conservation Area, and Price Conservation Area. The Colonel Roscoe Vanderwater Conservation Area offers the most complete recreational facilities, with provisions for swimming, boating, fishing, picnicking, camping and hiking.

Public swimming is also available at natural on-stream ponds, abandoned dams, and at small dams built for this purpose. Frequently used swimming holes are located in Cannifton, Corbyville, Tweed, and at Lazier's Dam and Riverside Park in Belleville (Figure 28).

Several stream sections are used for boating, canoeing, and fishing. One such section is on the Skootamatta River between Flinton and Actinolite. Other waterways suitable for boating and canoeing are located primarily on the Moira River below Stoco Lake.

Future recreational use of water will depend on water availability and quality. A dam at Lingham Lake on the Black River, Deerock Reservoir on Partridge Creek, and a dam at Skootamatta Lake on the Skootamatta River have improved availability of recreational waters in the Moira River, but this improvement has been negated somewhat by occasionally poor water quality. Natural and artificial inputs of nutrients, and the lack of sufficient water for circulation, have caused deterioration of water quality in Moira Lake and in the Moira River above the lake, thereby decreasing the recreational value of these waters. The construction of reservoir(s) to augment low streamflows in the Moira River above Moira Lake has been considered for some time and, if implemented, will undoubtedly improve the opportunity for recreational facilities along this length of the Moira River.

WATER RESOURCES PROBLEMS AND MANAGEMENT

Introduction

As villages and towns grow and population density in the watershed increases, the conservation and proper management of surface and ground waters, both in terms of quality and quantity, will become increasingly important. It is already obvious that problems of water quantity and quality, of varying degrees, exist in the watershed. In many instances, however, these problems are not insurmountable and more importantly, the prevention of similar problems in other areas of the basin is possible. In this chapter some of the more evident problems are discussed and fundamental management guidelines are suggested. These guidelines are offered as the basic principles that should be considered in order to avoid similar problems in as yet unaffected areas of the basin.

The most common water-related problem in the Moira River basin is inadequate supply. Inadequate ground-water supplies for domestic wells are frequent in the limestone areas of the basin, and the quantities of water obtainable in the Precambrian rock areas are unpredictable. The inadequacy of supplies is sometimes compounded by well interference, poor natural ground-water quality, and by the pollution of existing supplies.

Marginal streamflow in the Moira River and its main tributaries during the summer months limit the consumptive use of surface water, and the poor biological and bacterial quality can further restrict its use for non-consumptive activities.

The lower reaches of the Moira River have a long history of flooding during the spring.

Ground Water

Inadequate Water Supplies

Inadequate supplies due to insufficient amounts of water, or the poor quality of the water, is a serious concern in the basin. Dry wells and marginal water supplies occur frequently in Palaeozoic limestones in the southern parts of the basin (Map 7). In most instances, however, wells reported 'dry' are not literally without water, but rather yield supplies that are too small to be of practical use. Approximately 10 per cent of the wells in the limestone are reported as failures, i.e. 'dry', while about 50 per cent of the wells that do encounter water in the rock have yields estimated to be 2 gpm or less.

Drilling deeper in the limestone usually results in little, if any, increase in yields, and very often water of poor quality can be expected at depth. Unless a suitable supply is obtained at depths within approximately 50 feet of the limestone surface, the prospects of encountering an adequate supply of good quality water in the rock is poor.

In the Precambrian portion of the basin, approximately 5 per cent of the wells have failed to obtain adequate supplies of ground water for domestic needs. Not enough data are presently available to delineate areas where dry wells are most common but existing records do indicate that dry wells can be both shallow and deep. In some situations down-hole blasting

may enlarge or extend existing fracture and joint systems and thus increase well yields, but there is no guarantee of success by this method. Any attempts at enlarging fractures by this method should be made only by qualified, experienced personnel.

Yields in overburden are often marginal, especially in areas where the overburden is thin or where it consists of poorly permeable materials such as silt, clay or till. Low yields from overburden materials are evident throughout the greater part of the watershed, except in the overburden aquifers in the southern part of the basin (Map 6). Yields from deposits such as sand till and fine sands may be improved by constructing large-diameter bored or dug wells to provide greater storage, or failing this, wells may be drilled deeper to explore the possibility of obtaining usable quantities of water from shallow horizons in the bedrock.

In some areas, shortages of supply may be due to a continual over-use of ground water, resulting in the decline of water levels in the area. This situation may exist in the vicinity of small towns and communities where there is a heavy concentration of wells that obtain water from a common aquifer. Mining of the limestone aquifer has been detected at Thomasburg and Halton, two areas where bedrock wells draw water from approximately the same depths. In other small communities such as Foxboro, Latta, Marlbank, and Threshers Corners, where a number of domestic wells obtain water from common formations, mining of ground water may also be taking place.

Well Interference

Continual pumping of a well results in a cone of depression in the water-table or the piezometric surface in the vicinity of the well, and if other wells are located within this cone of influence, their water levels will also be lowered. This situation is termed 'well interference', and it has the effect of reducing the available drawdown and the potential yield of a well, and in severe cases may cause water levels to decline below the bottom of some shallow wells.

At Thomasburg and Halton, the effects of pumping in nearby wells in limestone have been noted on the hydrographs of observation wells 209 and 123 (Figure 4). Well interference has also been documented at Madoc where pumping of the municipal well affected the water levels in a number of nearby domestic wells, and probably occurs to some degree in other towns and villages where numerous domestic wells obtain water from the same water-bearing zone.

Interference can be expected to be more noticeable in bedrock wells than in those in overburden. The fracture and joint porosity of the rock is small and provides little storage, while the permeability may be quite large along the openings. This results in disproportionately large drawdown-yield ratios, with the result that relatively distant wells that tap the same fracture or joint system are affected. Because 90 per cent of the wells in the basin obtain supplies from bedrock, most of which are in limestone, interference must be regarded as a potentially serious problem in many parts of the basin.

Interference generally poses a lesser problem to wells in the overburden than to those in bedrock. The deposits of sand and gravel which comprise the kame moraine, and the sand deposits which extend along Palliser and Chrysal creeks, are areas where interference could be a problem if high-capacity wells were to be developed close to existing domestic wells. At the present, however, interference has not been detected in these areas.

Ground-water users must be aware of the problems caused by interference, and new wells should be located with some thought to avoid this. Insofar as it is practical, wells should be located as far apart as possible and should, in the case of water-table wells, be sufficiently deep to provide for adequate storage and drawdown. Interference will be most severe when a high-capacity well is installed in the midst of low-demand domestic wells, as in the case of the Madoc municipal well.

Flowing Wells

Only nine flowing wells have been reported in the basin (Map 5) and the problems caused by these wells are not serious. Three wells are constructed approximately 40 feet deep in a gravel deposit on the southeastern flank of the kame moraine between Frankford and Thomasburg; three others are constructed in shallow sand and gravel deposits adjacent to the Moira River south of Foxboro, and the remaining three are rock wells. Of the rock wells, two are in Belleville and both are approximately 240 feet deep; the third well (observation well 327) is near Foxboro and is 187 feet deep.

Any future wells that are drilled deep into the limestone or the underlying granites in the southern portion of the basin can be expected to flow. Similarily in the overburden, new wells to be drilled along the flanks of the moraine could flow. However, the conditions which produce shallow flowing wells in the overburden, such as those near Foxboro, are relatively local, and it is difficult to accurately predict their occurrence without a detailed knowledge of the local hydrogeology.

Unregulated flowing wells usually waste ground water, contribute in time to a general lowering of water levels in the vicinity of the wells, and may pose surface drainage problems. Where flowing conditions are anticipated, well casing should be firmly cemented at ground surface and the contractor must be prepared to take measures to control the discharge of water inside and outside the well casing. In the southern part of the basin where deep rock wells will probably flow, and where the overburden is thin, casing should be cemented in the interval from ground surface to several feet into solid limestone to prevent flow of water around the outside of the casing.

Poor Natural Water Quality

Figure 29 shows the locations of wells in which significant tastes, odours or natural gas were reported by the driller at the time of well construction. Approximately 8 per cent of the wells drilled in the basin have reported water quality problems, which include 'sulphurous', 'mineralized', and 'salty' waters, as well as occasional occurrences of natural gas. These are qualitative terms applied subjectively by the driller at the time of completion of the well.

Reports of sulphurous water are common and account for about 75 per cent of all reported ground-water quality problems in the basin. Most wells which report sulphurous water are located in the Palaeozoic limestones within a few miles of Lake Ontario. These waters presumably contain hydrogen sulphide gas, which has a characteristic 'rotten egg' odour. The gas can usually be removed by aeration and does not present a health hazard.

Occurrences of salty and highly mineralized ground water are confined primarily to the limestones, and in general ground-water quality is poor in the deeper limestone formations. Salinity increases markedly with increased depth, as indicated by the highly mineralized water in the 185-foot deep observation well 327 which contained almost 20,000 ppm of chloride and approximately an equivalent amount of sodium. For reasons of poor overall chemical water quality, including highly mineralized water and the occurrence of gas, wells should not be drilled deeper than 30 to 40 feet in limestone, especially in areas south of Foxboro.

Occurrences of natural gas are most frequent in wells penetrating limestone in the southern part of the basin. Natural gas was encountered during drilling of observation wells 327 and 256 (Map 2). In well 327 it was first encountered at a depth of about 50 feet, but whether or not any additional gas was found deeper in the hole is not known. In well 256, gas was first detected at approximately 60 feet. The presence of gas in these wells may be due either to the natural occurrence of small amounts of gas in the Palaeozoic formations, or to the migration of gas from other areas.

Gas has also been reported in two overburden wells, but it is not known whether these occurrences are of natural gas or that generated in swamps by organic material.

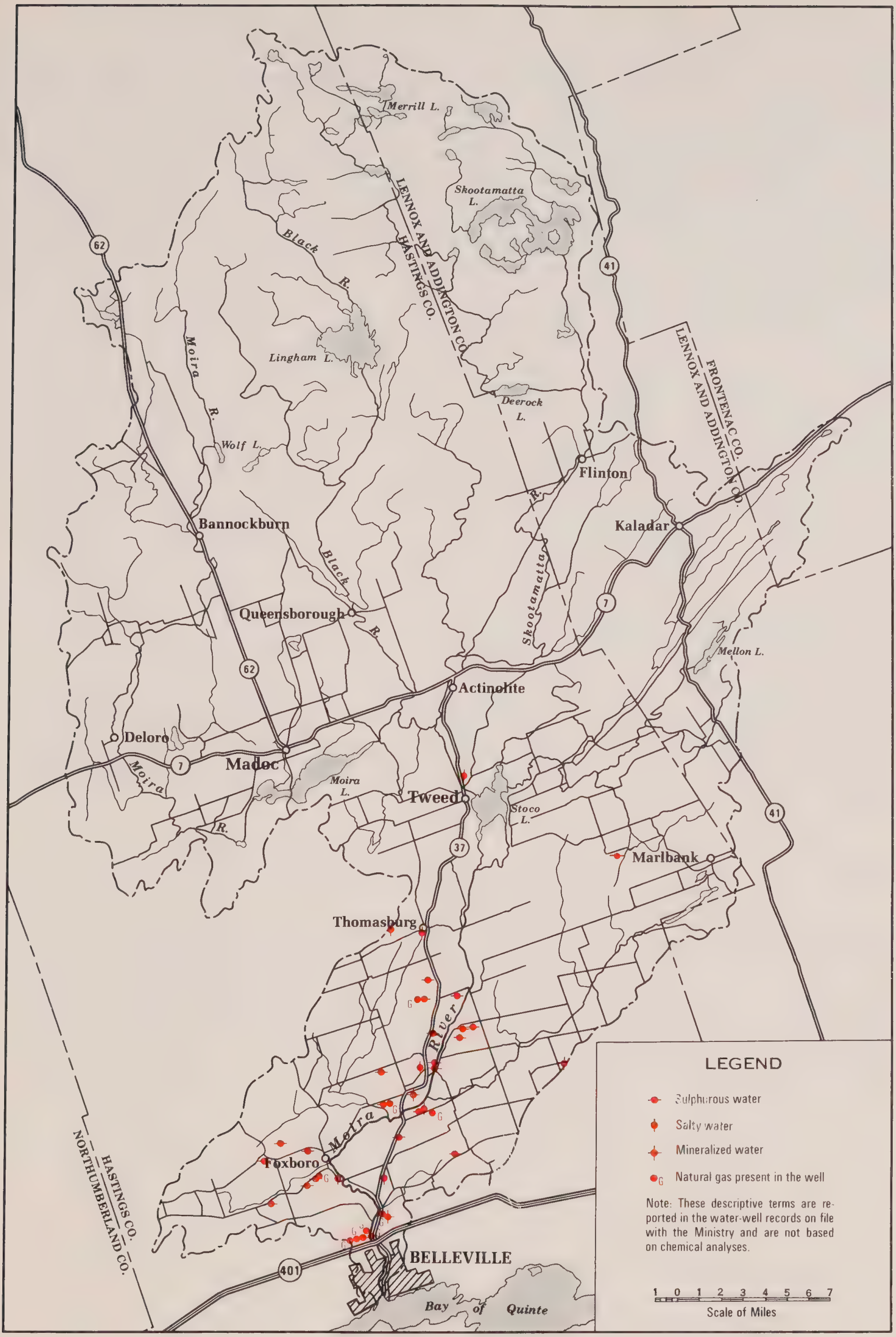


Figure 29. Locations of wells in the Moira River basin which were reported to yield water with significant taste and odour at the time of construction.

The presence of gas in water supplies is primarily a nuisance as it imparts no particular taste to the water. Its presence is a problem insofar as the gas must be removed before the water enters a pressure system because its accumulation may pose an explosion hazard. Adequate venting of the system must be provided.

Twenty-six of the 66 ground-water samples collected in the basin contained detectable amounts of arsenic. The reason for the presence of arsenic in these wells is not known; however, it is thought that in all cases the arsenic is naturally occurring. All samples contained less than the recommended maximum of 0.05 ppm for drinking water. Of the 26 wells, 20 contained less than 0.01 ppm arsenic and 8 contained between 0.01 ppm and .024 ppm. Four of these 8 samples were obtained from wells constructed in granite and 4 from wells completed in limestone.

Nitrate concentrations in excess of 45 ppm (as NO_3) are considered harmful to infants and may produce cyanosis, a listless, drowsy condition accompanied by blue coloration of the skin. A maximum permissible criteria of 45 ppm, and a desirable criteria approaching zero, are quoted by the Ministry of the Environment (1974) for nitrate concentrations in drinking water. This level of nitrate is usually harmless to older children and adults. As natural nitrate levels in ground water are usually low (generally less than 1 ppm), it is possible that a large proportion of those wells with nitrate concentrations in excess of about 5 ppm may be contaminated to some degree. Of the 66 wells sampled throughout the basin in 1969, 36 contained more than 5 ppm of nitrate (as NO_3) and 7 of these contained more than the recommended maximum of 45 ppm (Figure 30).

Pollution by Gasoline and Road Salts

Ground-water pollution by petroleum products has been reported at Millbridge, Madoc, and Cannifton. The disposal of waste petroleum products in a shallow pit at Cannifton polluted several nearby wells, while at Madoc, gasoline leakage from buried storage tanks contaminated several domestic wells, including a newly drilled municipal well. Ground-water pollution at Millbridge was due to leaking of gasoline from an old underground storage tank at a service station.

Gasoline pollution is a particularly serious threat to ground-water quality because concentrations of only a few parts per billion produce offensive odours and tastes in water supplies, and cleaning up of the pollution is difficult.

In many of the ground-water samples taken in 1969, chloride concentrations were deemed to be high (in excess of 50 ppm), and a closer investigation of each situation showed that at least eight wells were close enough to salted roads to be possibly affected by meltwaters containing high concentrations of chlorides. Only two wells (1081 and 3369) contain high enough chloride concentrations to possibly render a salty taste to the water. Four of the eight wells suspected of being contaminated by road salts are completed in limestone and four are in igneous and metamorphic rock areas.

The following are some relevant data on the eight wells:

Well No.	Well Depth (ft)	Chloride Content (ppm)	Reported Water Quality (by driller)
1081	100	237	fresh
1104	40	126	not fit for human consumption
717	39	95	not tested
463	75	101	fresh
554	77	45	salty
3369	48	248	sulphur
3303	85	96	sulphur
100	19	92	fresh

The reason for the 'not fit for human consumption' classification by the driller for well 1104 is not known, and the water in well 554 did not contain any elements of high enough concentration in August 1969 to warrant the 'salty' classification.

At most of the eight well locations, the drift cover is reported to be less than 10 feet, which suggests that any contaminated surface water such as meltwater from roads has a relatively easy access into bedrock, and subsequently into ground water. Fortunately, the effects of salt contamination will decrease fairly rapidly with increased distance from salted roads, and usually no trace of contamination can be detected within several hundred feet from a road.

To minimize the chances of salt contamination, wells should be located on high ground and as far away as possible from salted roads. In situations where existing wells are at elevations lower than the road, a cement seal around the well collar will help to minimize surface leakage of salty meltwater directly into the well.

Surface Water

Arsenic Contamination

Concentrations of arsenic in excess of 0.05 ppm (permissible criteria for potable water [Ontario Ministry of the Environment, 1974]) have occurred in Moira and Stoco lakes and in the Moira River downstream of Deloro as far south as Thomasburg. The source of this contamination has been traced to the property of Deloro Mining and Smelting Company in Deloro (Owen and Galloway, 1969), where buried mine tailings containing arsenic are leached by precipitation and ground water and the leachate is discharged naturally into the Moira River. Since 1970, the Company has undertaken measures to reduce the amount of contaminated ground water from reaching the Moira River, and the latest data (1971) indicate a reduction in arsenic concentrations in the river directly below Deloro. A detailed account of the occurrence of arsenic in surface waters in the basin has been made by Owen and Galloway (1969).

Poor Biological and Bacterial Quality

The biological quality of surface waters was not investigated during the field survey in 1969, but a related study was carried out by Owen and Galloway (1969) in 1967. A summary of their findings follows.

A persistent problem in some surface-water bodies in the basin is caused by excessive blooms of blue-green algae that have occurred frequently in Moira and Stoco lakes, and are a common sight in swamps located on the Canadian Shield. The blooms are commonly found in the more stagnant bodies of water and are seldom, if ever, seen in fast flowing streams. Owen and Galloway conclude that most of the nutrient (phosphorus and nitrogen) necessary for algal growth in the Moira and Stoco lakes is derived from natural runoff in the watershed rather than from domestic waste discharged into them. Algal blooms have not been noted in the large northern-most lakes in the basin.

Excessively high total coliform counts were found in various surface-water samples taken during July and August of 1967. The most notable of these occurred in Jordan River below Millbridge, and at various locations in Moira Lake. At least one public beach on Stoco Lake has been closed on a number of occasions due to high bacterial levels. This beach is adjacent to the Tweed sewage outfall into the lake, which is the probable source of the coliform contamination. Improved treatment facilities for the town are expected to reduce this contamination.

Stream Water Shortages

Demands for stream water by industry and agriculture have occasionally exceeded streamflows in the Moira River during the summer. Corby's Distillery Limited in Corbyville, which obtains a large portion of its water supply during the summer from the Moira River, has had to suspend its operation on several occasions due to low streamflows. This company takes up to two million gallons of water per day (about 4 cfs) from the river for use in its cooling system. The water is returned to the river at a relatively high temperature, and during some low flows there has been insufficient water to adequately assimilate the heated water discharged from the plant. The stream-water shortages experienced by Corby's Distillery Limited have been averted in recent years by releasing additional water from Lingham and Skootamatta lakes.

Another instance of inadequate stream water was related by a resident proposing to use Moira River water near Eldorado for irrigation. However, the project had to be abandoned when it was learned that flows in the river during July and August would be insufficient to meet his demands. To avert future shortages of this type in the upper sections of the Moira River, the Moira River Conservation Authority has recommended that two small reservoirs be built and operated to augment low summer flows. One will be on the Jordan River below Jordan Lake and the other on Gawley Creek in Lot 25, Concession 10, in the Township of Marmora.

In its comprehensive plan to provide more stream water for recreation, industry, domestic water supply and pollution abatement, the Moira River Conservation Authority has proposed the construction of two other reservoirs in addition to those on the Jordan River and Gawley Creek. The largest is on the Moira River near Bend Bay and will have a total capacity of 62,500 acre-feet. Part of its capacity will be used to store water to maintain a minimum summer discharge of 175 cfs downstream. The other proposed reservoir is in the headwaters of the Skootamata River; however, at present a site has not been chosen for it.

Still another alternative being mentioned by the Authority to provide more water for streamflow augmentation is to raise the height of the Lingham Lake dam by one to four feet. If all the additional storage is used for streamflow augmentation, flows in the Black River would be increased by 14 to 56 cfs during a 90-day period of low flows in the Moira River during the summer.

Flooding

Flooding along the Moira River is a serious problem. Flooding in the watershed has been documented by the Department of Planning and Development (1950), and the following section on floods is a general summary of their findings. Additional information on floods was obtained through personal communications with the Ministry of Natural Resources at Tweed.

All serious floods in the basin have occurred in the spring when runoff is usually at its annual high. In the spring of 1936, flooding at Belleville left one person dead, 200 homeless, and property losses were estimated to be as high as $250,000. Although floods are sometimes caused solely by high runoff, ice jams in the lower sections of the Moira River, together with high spring flows, have been the main cause of flooding. For example, the 1936 flood, the worst on record in Belleville prior to 1950, was caused by an ice jam which started on about March 10. On March 13 and 14 when most of the damage by the flood occurred, the average flow at the Foxboro gauge was less than 4000 cfs. In comparison, the discharge on March 31, 1936 was more than three times as high as on March 13 and 14 (12,400 cfs), but no serious flooding was reported on this day.

Apart from damage caused by flood waters, substantial damages have been caused by river ice during spring floods. This damage has usually been in the form of damaged or destroyed bridges, damage to private property along the Moira River, and substantial streambank erosion.

Periodic flooding has also occurred at Madoc and Tweed, and floods have inundated considerable acreages of farmland between Cannifton and Foxboro.

The Moira River Conservation Authority has recommended that an ice-control dam–the College Street dam–be built on the Moira River above Belleville to relieve ice jams in Belleville. It has also recommended that a portion of the capacity of the proposed Bend Bay reservoir be reserved to control spring runoff from the upper section of the river when flooding is anticipated downstream. The proposed reservoir on the Skootamatta River and the additional storage capacity in Lingham Lake will also serve to control floods, but at present the amount of flood storage in these reservoirs is not known.

SUMMARY

Surface- and ground-water resources in the Moira River basin are evaluated in terms of occurrence, distribution, quantity and inorganic chemical water quality. A brief inventory of water use is also presented, together with a discussion of the more significant water quantity and quality problems for which basic management principles and guidelines are suggested.

The survey was carried out in 1969 and 1970, during which time field work consisted of limited geologic mapping, stream gauging, the exploration for ground water through test drilling, the installation of observation wells, stream gauges, and a pan evaporation station near Stoco Lake, and water sampling for inorganic chemical analyses.

The Moira River and its tributaries drain 1060 square miles and empty into Lake Ontario at Belleville. There are two major physiographic regions in the basin, one in the north and the other in the south, which in general conform to the two major geologic environments in the watershed: the northern region is characterized by Precambrian bedrock topography of the Canadian Shield, and the southern region displays overburden glacial features on Palaeozoic limestones. The northern portion of the basin consists primarily of bedrock outcrops, swamps, and lakes in a rugged terrain typical of the Canadian Shield. The southern regions are typified by rolling topography created by generally thin glacial deposits on limestone bedrock. The Shield regions are, for the most part, uninhabited with most of the settlement concentrated in the southern half of the basin.

The basin is drained by four main tributaries of the Moira River: the Skootamatta, Black and Clare rivers, and Parks Creek. The Skootamatta and Black rivers combined drain about 40 per cent of the watershed; Clare River and Parks Creek drain another 20 per cent, and the remaining 40 per cent is drained by the Moira River and its smaller tributaries.

The four largest lakes in the basin—Skootamatta, Lingham, Moira and Stoco—make up nearly 70 per cent of the total surface area of the 19 large lakes in the watershed that have surface areas greater than 100 acres.

Climate is variable in the watershed. Generally lower daily temperatures occur in the northern parts of the basin than in the south, and the highest annual precipitation has been recorded near the centre of the basin at Tweed. The annual mean daily temperatures range from 40.2°F at Bancroft to 45.8°F at Belleville and the mean annual precipitation at Tweed is 34.5 inches.

Precambrian metamorphic and plutonic rocks underlie the whole of the basin. They outcrop in the north and underlie Palaeozoic limestones of the Trenton and Black River groups in the southern parts of the basin. Usually thin deposits of glacial overburden materials mantle both the Precambrian rocks in the north and the Palaeozoic limestones in the south. The glacial overburden materials consist of sands and gravels in outwash deposits and in eskers and kame moraines, of stony sand till in the Dummer moraine and the drumlinized till plain areas south of Tweed, and of sand, silt and clay in the lacustrine plain areas north of Belleville.

There are three general hydrogeologic units in the basin:

(1) overburden
(2) Palaeozoic limestones, and
(3) Precambrian rocks.

Of approximately 4000 wells in the basin on record with the Ministry of the Environment, approximately 10 per cent are constructed in overburden materials, 80 per cent obtain water from limestone, and 10 per cent are drilled in Precambrian rocks.

There are two known areas in the basin where overburden aquifers are significant. One area is along the southwestern boundary of the basin where kame sands and gravels are present, and the other area adjoins the kame deposits and contains outwash and lacustrine sands that extend eastward along Chrysal and Palliser creeks, and along Parks Creek. Well yields throughout these two areas commonly range between 2-10 gpm, and higher yields are possible where the sands and gravels are thick.

Limestones of the Trenton and Black River groups are considered as a single water-bearing unit and are the most common source of ground water in the basin. Yields to most wells are less than 2 gpm, which is only marginally adequate for domestic uses. However, there are scattered areas north of Madoc, south of Tweed, and north of Belleville where well yields are reported to exceed 10 gpm.

The occurrence of ground water in Precambrian rocks is very unpredictable and yields to wells vary considerably. Several hundred gallons per minute are obtained from deep municipal wells at Tweed and Madoc, but most domestic wells receive less than 2 gpm. In general the rocks of the Precambrian hydrogeologic unit are not a predictably reliable source of ground water.

Eighteen observation wells have been established in the basin; six in overburden, eleven in limestone, and one in Precambrian rock. In all wells the water levels were found to be highest during the spring months of March, April and May, and usually lowest during September and October. The largest amplitudes of fluctuation were in wells in limestone, which reached very high, sharp peaks during the spring. In two of the limestone wells—123 and 209—water-level interference by nearby domestic wells was evident.

Correlation of ground-water levels with base flow in streams produced a regression curve between water levels in well 122 and base flow at gauge 02HL001 on the Moira River at Foxboro. Curves applicable to summer months only correlate water levels in wells 229, 123 and 210, and base flows at streamflow gauging stations 02HL004 on the Skootamatta River, 02HL103 on Parks Creek, and 02HL003 on the Black River, respectively. All these regression curves can be used to assist in estimating base flow on respective streamflow hydrographs.

Surface water inventory consists of presenting annual, monthly and daily variations in streamflow, and of flow-duration and minimum- and maximum-flow analyses for discharges on the Moira River and its tributaries of Skootamatta, Black and Clare rivers, and Parks Creek.

There are eight streamflow recording stations in the basin, with the farthest downstream station being on the Moira River at Foxboro. This station records discharge from 98 per cent of the watershed and the discharge at this gauge is taken to represent the total flow from the 1060 square mile area of the basin. Streamflow data on the Moira River at station 02HL101 near Tweed, and 02HL104 near Thomasburg, have not been analyzed because of discrepancies in data at both stations.

The mean annual discharge over a period of 54 years of data at the Foxboro gauge on the Moira River is 1040 cfs, of which the Skootamatta River singly contributes the largest portion—29 per cent or 305 cfs. Other large contributors are the Black River with 175 cfs and the Moira River above Deloro with 120 cfs.

Highest monthly mean flows in most streams occur in April and the lowest in September. The monthly mean discharges for April are 4050 cfs for 54 years of data at the Foxboro gauge on the Moira River, 1010 cfs and 544 cfs at gauges on the Skootamatta (11 years of data) and Black (14 years of data) rivers, and 347 cfs at the Deloro gauge on the Moira River (5 years of data). The monthly mean discharges in September are 117 cfs at Foxboro, 43 cfs at the Black River gauge, 28 cfs at the Skootamatta River gauge, and 6 cfs at Deloro.

Daily mean flows indicate similar seasonal trends as the monthly flows, with large discharges during the spring runoff periods and progressively smaller flows during the summer months. The lowest daily flow recorded at the Foxboro gauge has been 15 cfs, and 10 per cent of the time the daily discharge at this gauge is less than 61 cfs. The lowest daily discharges recorded at the outlets of the upper Moira River, Black, and Skootamatta rivers have all been less than 2 cfs. Summer flows in tributaries are less than 1 cfs. During low-flow periods, most of

the water in the Moira River downstream of Stoco Lake is derived from the Black and Skootamatta rivers.

Streamflow augmentation and control of flood flows is accomplished by dams at the outlets of five large lakes: Lingham, Moira, Skootamatta, Deerock and Stoco. Water releases from Lingham and Skootamatta lakes during summer low flows have been most noticeable in the past in streamflow hydrographs for the Black and Skootamatta rivers.

Flow-duration analyses on the major tributaries and the Moira River itself indicate that generally little water is derived from surface- or ground-water storage during summer low-flow periods, while storage in most sub-basins does moderate some peak flows. Because of the low perennial yields available from storage, daily flows exceeded 90 per cent of the time, i.e., low flow, in most headwater tributaries are less than 1 cfs. The 90 per cent daily flows in all streams, except in the lower reaches of the Moira, the Black and the Skootamatta rivers, are less than 10 cfs.

The minimum daily discharge on record at the Foxboro gauge on the Moira River has been 15 cfs ($T = 40$); zero daily flows have been recorded at the gauge on the Black River, and 0.6 cfs at the gauge on the Skootamatta River.

The maximum 1-day flow on record at the Foxboro gauge has been 12,400 cfs ($T = 50$), while the 1-day maximum flows on record at gauges on the Black and Skootamatta rivers have been 2210 cfs ($T = 10$) and 2660 cfs ($T = 3.8$), respectively.

Evapotranspiration (*ET*) losses in the basin were estimated and compared using a method outlined by Thornthwaite (1948) and another proposed by Konstantinov (1963). The results obtained by the Konstantinov approach were deemed to be more applicable in the basin and the method was subsequently used to calculate *ET* in five water-year hydrologic budgets —from 1966 to 1970. An average budget over these five years is (all values in inches):

$$\text{PRECIPITATION} = \text{TOTAL RUNOFF} + ET \pm \Delta S$$
$$35.7 = 14.0 + 23.5 - 1.8$$
and
$$\text{TOTAL RUNOFF} = \text{DIRECT RUNOFF} + \text{GROUND-WATER RUNOFF}$$
$$14.0 = 10.0 + 4.0$$

ΔS is a value needed to balance the budget and represents cumulative errors in measurement of PRECIPITATION and TOTAL RUNOFF, and in estimating *ET*. It also includes the net changes in ground- and surface-water storage over the five-year period. The average precipitation of 35.7 inches is approximately 4 per cent greater than the 30-year normal (1931-1960) precipitation at Tweed, and the average runoff of 14 inches exceeds the long-term mean streamflow at Foxboro by about 6 per cent.

An estimate of Stoco Lake evaporation in 1970 indicated that water losses by evaporation from all the lakes in the basin amounted to about 100 cfs, or approximately 10 per cent of the annual mean flow of 1040 cfs out of the basin.

A total of 124 samples were collected in August 1969 for inorganic chemical analysis: 29 samples from 10 lakes, 28 samples from 11 different streams, 66 samples from wells, and 1 sample of rainwater. Lake waters contain the least amount of dissolved solids and can be divided into two distinct groups. There are four lakes in the first group: Merrill, Skootamatta, Deerock, and Mellon. All are located on the Canadian Shield and contain very low mineralization—the mean Total Dissolved Solids (*TDS*) concentration for the four samples was 40 ppm, which is close to the *TDS* concentration of 28 ppm found in the one rainwater sample collected at Tweed. The second group contains six lakes: Wolfe, Jarvis, Moira, Stoco, and Dry, and the Bay of Quinte (Lake Ontario). The mean *TDS* concentration for these lakes was more than four times the mean value for the first group—167 ppm. All lake waters were found to be of Ca-HCO_3 type.

Stream waters can also be categorized into two distinct groups: seven water samples obtained from streams in the Black and Skootamatta river basins belong in the first group and

have a mean *TDS* of 55 ppm. Streams in the second group are distributed throughout the rest of the watershed and contain appreciably higher *TDS*—a mean of 200 ppm for 21 samples from nine streams. As in lake waters, all stream waters are of Ca-HCO_3 type.

Surface waters generally contain little dissolved inorganic chemicals, but the high bacterial count in some lakes and streams, notably in Moira and Stoco lakes, and certain portions of the Moira River itself, indicates varying degrees of pollution of these waters, and consequently restricts their use for consumption and some recreational activities.

Ground water in general contains appreciably greater amounts of dissolved solids than surface waters, and the inorganic chemistry of ground waters in different geologic environments is distinctive. The least mineralized waters occur in igneous rocks—mean *TDS* for nine samples was 214 ppm. The highest mineralized waters occur in limestone wells in the southern parts of the basin where the mean *TDS* for four samples was 1470 ppm. Except for these four latter samples from limestone, all of the ground waters are of Ca-HCO_3 type. The exceptions consist of two samples of Ca-SO_4 type, and two of Na-Cl type waters.

Ground water in deep limestone wells in the extreme southern parts of the basin is generally of poor quality and not suitable for domestic use.

An inventory of existing water uses in the basin indicates that surface water is used primarily for recreation and sewage assimilation, and ground water serves water-supply needs of inland municipalities and the rural domestic population. Four municipalities have communal water-supply systems: Belleville, Tweed, Madoc, and Deloro. Belleville's system is the largest and has a rated capacity of 12.0 mgd, which is obtained from the Bay of Quinte in Lake Ontario. The other three municipalities utilize ground water; the Tweed system is the largest with a rated capacity of 0.44 mgd, followed by Deloro with a capacity of 0.36 mgd and by Madoc with 0.33 mgd. Almost all of the rural domestic water needs are satisfied by ground water, with only a very small percentage of users obtaining lake and river water for household uses.

All the municipalities that have communal water distribution also have municipal sewage treatment systems. The system at Belleville is the largest with a design capacity of 8.0 mgd, followed by Madoc with a capacity of 0.36 mgd, and by Tweed and Deloro with capacities of 0.18 and 0.08 mgd, respectively.

The need for management of surface- and ground-water resources for optimal benefit is obvious in many instances. Problems associated with ground water usually relate to either quantity or quality and some basic management guidelines are offered to overcome or prevent such problems. Five general ground-water problems are discussed:

1. inadequate supplies
2. well interference
3. flowing wells
4. poor natural water quality
5. ground-water pollution by gasoline and road salts.

Since limestone is the most common source of ground water for potable supplies, the inadequacy of supplies relates mainly to yields available from limestone wells. Within the limestone areas in the basin, most well yields are less than 2 gpm, which is only marginally adequate for domestic uses. About 10 per cent of the wells drilled in limestone have been reported dry.

Well interference was detected in two observation wells in limestone, one in Thomasburg and the other in Halton. The reduction of water levels in the observation wells are attributed to nearby domestic pumping wells. It is suspected that well interference in other limestone wells also exists, especially where a concentration of wells obtain water supplies from the same limestone formation.

There are no predictably extensive flowing well areas in the basin; only 9 of the close to 4000 wells on file with the Ministry of the Environment have been reported flowing. Six of these wells are constructed in overburden and 3 in limestone.

Natural water quality problems consist of 'sulphurous', 'mineralized' and 'salty' water, as reported by water-well drillers at the time of well construction, and natural gas has been reported in some limestone wells in the southern parts of the basin. Sulphurous waters, characterized by the 'rotten egg' smell of hydrogen sulphide, are most common with a number of highly mineralized and salty waters reported mainly from the deeper limestone formations in the south. A few wells sampled during the study contained detectable amounts of arsenic but all concentrations are less than the permissible criteria of 0.05 ppm for domestic supplies.

Seven of the 66 ground-water samples contained nitrate concentrations in excess of the 45 ppm NO_3 permissible criteria for domestic supplies.

There have been a number of reported cases of ground-water pollution by gasoline, notably at Millbridge, Madoc, and Cannifton, but in most instances the pollution has been localized to nearby wells with no far-reaching effects over large areas. The pollution case at Madoc included the contamination of a newly drilled municipal well in 1971, and as of this date (1974), the problem has not been solved satisfactorily.

A number of ground-water samples were found to contain unusually high chloride concentrations that are thought to be due to contamination by highway salting during the winter. In each case, however, the chloride concentrations are below the permissible criteria of 250 ppm and it is not expected that a noticeably salty taste is present in the water.

The management of surface-water resources in the watershed must deal with inadequate streamflows in the Moira River and some of its main tributaries, poor biological and bacterial water quality in some lakes and streams, and with flooding problems during the spring months in Belleville.

The most widespread problem in surface water relates to low streamflows in the Moira River north of Deloro and in some reaches of the river south of Stoco Lake. This places a restriction on the use of the river for recreational activities during summer low-flow periods, and a series of storage dams in the basin are being planned to augment streamflow as necessary.

Excessive blooms of blue-green algae and high coliform bacteria counts have occurred in Moira and Stoco lakes, the two most heavily used recreational lakes in the basin. These situations have restricted the enjoyment of boating, swimming and other water-based activities on the lakes, and have probably affected tourism to some degree in each area. Reduced nutrient inputs into the lakes would reduce the algal blooms, while increased treatment of Madoc and Tweed sewage will help to reduce bacteria concentrations in each lake.

All serious floods in the basin have occurred in the spring. High streamflow, together with ice jams on the Moira River, have created frequent flooding at Belleville and inundated low-lying farmland between Cannifton and Foxboro. Periodic spring flooding has also been reported at Madoc and Tweed. Flood-control dams at Belleville and at Bend Bay on the Moira River between Stoco and Moira lakes have been proposed and should provide protection to areas that have suffered flood damages in the past.

Surface-water resources will play an increasingly important role in recreational activities in the basin, and the conservation of the resource in terms of quantity and quality should be a prime objective in management planning. Stream-flow augmentation programs have been initiated and should improve downstream flows in the Moira River. However, land settlement and use policies, whether for permanent residents or for seasonal recreationers, must consider the conservation of the quality of surface water as important as its quantity. With the inevitable increased use of the resource, the formulation of 'total resource' management policies is basic if optimum water use is to be realized in the future.

SELECTED BIBLIOGRAPHY

Abell, H.C., 1963, Study No. 7—Some characteristics of low-income people; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/7.
Beards, R.J., 1967, Guide to the subsurface Palaeozoic stratigraphy of southern Ontario; Ont. Dept. Energy and Res. Mangt., Paper 67-2.
Brown, D.M., McKay, G.A., and Chapman, L.J., 1969, The climate of southern Ontario; Can. Dept. Transp., Met. Br., Climatological Study No. 5.
Bruce, J.P., and Weisman, B., 1967, Provisional evaporation maps of Canada; Can. Dept. Transp., Met Br., Cir. 4531.
Canada Department of the Environment, (?), Temperature and precipitation, 1941-1970, Ontario; Atm. Env. Serv.
Canada Department of Transport, 1965, Precipitation normals for Ontario; Met. Br., CDS #9-65.
________, 1968, Climatic normals; Met. Br., Vol. 1.
________, 1968, Climatic normals; Met. Br., Vol. 2.
________, 1970, Climatological station data catalogue-Ontario; Met. Br., CLI 5-70.
Chapman, L.J., and Putman, D.F., 1966, The physiography of southern Ontario; U. of T. Press.
Chow, V.T., 1964, Handbook of applied hydrology; McGraw-Hill.
Christiansen, J.E., 1966, Estimating evaporation and evapotranspiration from climatic data; Utah Water Res. Lab., Utah State U.
Coleman, A.P., 1936, Lake Iroquois; Ont. Dept. Mines, Annual Rept., Vol. XLV, Part VII, pp. 1-36.
________, 1936, Geology of the north shore of Lake Ontario; Ont. Dept. Mines, Annual Rept., Vol. XLV, Part VII, pp. 37-74.
Cruff, R.W., and Thompson, T.H., 1967, A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments; U.S. Geol. Surv., Water Supply Paper 1839-M.
Dalrymple, T., 1960, Flood frequency analysis; U.S. Geol. Surv., Water Supply Paper 1543-A.
Ferguson, H.L., et al., 1970, Mean evaporation over Canada; Water Res. Research, Vol. 6, No. 6, pp. 1618-1633.
Garrels, R.M., and Christ, C.L., 1965, Solutions, minerals and equilibria; Harper and Row
Harding, W.D., 1942, Geology of Kaladar and Kennebec townships; Ont. Dept. Mines, Annual Rept., Vol. LI, Part IV, pp. 51-74.
Hewitt, D.F., 1964, Geological notes for maps Nos. 2053 and 2054 Madoc-Gananoque area; Ont. Dept. Mines, Geol. Cir. 12.
________, 1966, Geological notes for map 2117; Ont. Dept. Mines, Geol. Cir. 15.
________, 1968, Geology of Madoc Township and the north part of Huntingdon Township; Ont. Dept. Mines, Geol. Rept. 73.
Hills, G.A., 1963, Study No. 1—Land and water resources; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/1.
Hore, F.R., (?), Farm water supply; Ont. Min. Agric. Food, Publ. 476.
Hvorslev, M.J., 1951, Time lag and soil permeability in ground water observations; U.S. Army Corps of Engineers, Waterways Expt. Sta., Bull. No. 36.

Johnson, M.G., and Owen, G.E., 1970, The role of nutrients and their budgets in the Bay of Quinte, Lake Ontario; Ont. Water Res. Comm.

Kohler, M.A., Nordenson, T.J., and Fox, W.E., 1955, Evaporation from pans and lakes; U.S. Weather Bureau, Res. Paper #38.

Liberty, B.A., 1960, Belleville and Wellington map-areas, Ontario; Geol. Surv. Can., Paper 60-31.

________, 1960, Rice Lake-Port Hope and Trenton map-areas, Ontario; Geol. Surv. Can., Paper 60-14.

________, 1963, Geology of Tweed, Kaladar and Bannockburn map areas, Ontario, with special emphasis on Middle Ordovician stratigraphy; Geol. Surv. Can., Paper 63-14.

Lumbers, S.B., 1969, Geology of Limerick and Tudor townships; Ont. Dept. Mines, Geol. Rept. 67.

MacGregor, M.A., and Braithwaite, W.M., 1963, Study No. 2—Sources and levels of income of open-country residents; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/1.

________, 1963, Study No. 5—Some economic aspects of recreational resource uses; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/5.

MacLaren, James F., Ltd., 1971, Interim report to the Ontario Water Resources Commission on the problem of arsenic contamination at the Deloro Stellite Mine site; James F. MacLaren Ltd., Toronto.

Meen, V.B., 1942, Geology of the Grimsthorpe-Barrie area; Ont. Dept. Mines, Annual Rept., Vol. LII, Part IV, pp. 1-50.

Meyboom, P., 1967, Groundwater studies in the Assiniboine River drainage basin, Part II; Geol. Surv. Can., Bull. 139.

Miller, W.G., and Knight, C.W., 1914, The Pre-Cambrian geology of southeastern Ontario; Ont. Bureau Mines Rept., Vol. XXII, Part II.

Mirynech, E., 1962, Pleistocene geology of the Trenton-Campbellford map-area, Ontario; unpub. Ph.D. thesis, U. of T.

________, 1967, Pleistocene and surficial geology of the Kingston-Cobourg-Tweed area, Ontario, *in* Guidebook-Geology of parts of eastern Ontario and western Quebec; G.A.C., M.A.C., M.A.A., pp. 183-198.

Ontario Department of Agriculture and Food, 1966, The climate of Ontario; Statistics Section.

Ontario Department of Economics and Development, 1968, Lake Ontario region economic survey.

Ontario Department of Planning and Development, 1950, Moira Valley Conservation report.

________, 1950, Moira Valley conservation report—summary and recommendations.

________, 1955. Moira Valley conservation report.

Ontario Ministry of the Environment, 1974, Guidelines and criteria for water quality management in Ontario.

Ontario Ministry of Treasury, Economics and Intergovernmental Affairs, 1975, Municipal Directory.

Ontario Water Resources Commission, 1971, Water pollution survey of the Village of Deloro, County of Hastings; Division of Sanitary Engineering.

Owen, G.E., and Galloway, D.L., 1969, Biological survey of the Moira River; Ontario Water Resources Commission, Biology Br.

Philpotts, L.E., 1963, Study No. 8—Aerial photo interpretation of land use changes; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE-63-4/8.

Potter, J.G., 1966, A catalogue of climatological stations in Ontario; Can. Dept. Transp., DS #21-66.

Riggs, H.C., 1968, Some statistical tools in hydrology; U.S. Geol. Surv., Tech. of Water-Res. Invest., Chapter A1, Book 4.

Rodd, R.S., 1966, Study No. 9—Economic growth and transition; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-65-66/9.

Sanford, B.V., 1961, Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; Geol. Surv. Can., Paper 60-26.
Schoeller, H., 1959, Arid zone hydrology—recent developments; UNESCO, Paris.
Scott, H.K., and Garland, S.W., 1963, Study No. 3—Industrial development survey; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/3.
———, and Lussier, J.G., 1963, Study No. 4—Plans and attitudes of high school students; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/4.
Searcy, J.K., 1959, Flow-duration curves; U.S. Geol. Surv., Water Supply Paper 1542-A.
Swinnerton, A.C., 1942, Hydrology of limestone terraines, *in* Hydrology by O.E. Meinzer; Dover Publ., pp. 656-677.
Szesztay, K., 1968, Determination of evapotranspiration on the basis of air temperature and vapour content, *in* The Hydrologic cycle and the water balance in nature by Kienitz et al., 1968; Manual Number 8, Lecture Notes Subject 7, Research Inst. for Water Res. Devt., Budapest.
Thornthwaite, C.W., and Mather, I.R., 1955, The water balance; Drexel Inst. Tech., Lab. Clim., Vol. VIII, No. 1.
U.S. Environmental Protection Agency, 1971, Environmental impact of highway de-icing; Water Quality Office, Water Poll. Control Res. Series 11040 GKK.
deVos, A., and Holder, A.S., 1963, Study No. 6—Fish and wildlife base of recreational resources; Dept. Agric. Ec., O.A.C., Guelph, Ref. No. AE.-63-4/6.
Wilson, M.E., 1940, Madoc; Can. Dept. Mines Res., Map 559A.
———, 1940, Marmora; Can. Dept. Mines Res., Map 560A.
Winder, C.G., 1955, Campbellford map-area, Ontario; Geol. Surv. Can., Paper 54-17.
World Meteorological Organization (WMO), 1966, Measurement and estimation of evaporation and evapotranspiration; Secretariat of the World Met. Org., Geneva, Tech. Note No. 83.

NOTE: Continuous streamflow data in the basin has been published since 1919 by a number of departments in the Federal Government of Canada. Presently, they are published by Canada Department of the Environment. Prior to 1919, this data was compiled by the Hydro-Electric Power Commission, Province of Ontario.

APPENDIX A

History of Observation Wells in the Moira River Basin, 1974

TOWNSHIP ABBREVIATIONS

El	—Elzevir
Hu	—Hungerford
Hun	—Huntingdon
Ka	—Kaladar
Ma	—Madoc
Th	—Thurlow
Ty	—Tyendinaga

Table 16. History of Observation Wells in the Moira River Basin, 1974
(Locations of wells shown on Map 2)

Well Number	Location			Type	Finished Diameter (inches)	Depth (feet)	Aquifer or Formation	Period of Record	Type of Record; Recorder	Notes (Ground elevations are approximate geodetic elevations in feet above mean sea level)
	Township	Concession	Lot							
122	Th	VI	22	dug, overburden	48	30	sand till	since Feb. 18, 1965	continuous; Stevens Type F	ground elevation—392; in Moira River drainage area; on Moira River Conservation Authority property
123	Ty	VI	7	drilled, rock	6	72	limestone	since Feb. 18, 1965	continuous; Stevens Type F	ground elevation—459; in Parks Creek drainage area; on Moira River Conservation Authority property
157	Hu	III	5	dug, overburden	36	14	sand(?)	since July 20, 1965	periodic measurements	ground elevation—435; in Moira River drainage area; on Moira River Conservation Authority property
158	Hu	II	5	drilled, rock	6	58	limestone	since Sept. 22, 1965	periodic measurements	ground elevation—439; in Moira River drainage area; on Moira River Conservation Authority property
161	El	IV	3	drilled, rock	6	37	limestone	since Sept. 22, 1965	periodic measurements	ground elevation—532; in Skootamatta River drainage area; on Moira River Conservation Authority property
162	Ma	III	6	dug, overburden	48	16	sand till(?)	since Sept. 16, 1965	periodic measurements	ground elevation—649; in Moira River drainage area; on Moira River Conservation Authority property
163	Ma	III	6	drilled, rock	6	40	limestone	since Sept. 22, 1965	periodic measurements	ground elevation—666; in Moira River drainage area; on Moira River Conservation Authority property
209	Hu	V	1	drilled, rock	6	71	limestone	since Nov. 28, 1967	continuous; Stevens Type F	ground elevation—571; in Moira River drainage area; on Moira River Conservation Authority property

210	Ma	X	1	drilled, overburden	6	21	sand(?)	since Nov. 28, 1967	continuous; Stevens Type F	ground elevation—555; in Moira River drainage area; on Moira River Conservation Authority property
229	Ka	II	23	dug, overburden	48	17	sand	since May 2, 1969	continuous; Stevens Type A35	ground elevation—801; in Skootamatta River drainage area; on Mr. Blackwell's property
230	Ma	V	28	drilled, rock	6	40	paragneiss	since June 24, 1969	continuous; Stevens Type F	ground elevation—821; in Moira River drainage area; on Mr. W. E. Harris' property
256*	Th	VI	22	drilled, rock	6	187	143 feet limestone	since June 22, 1970	continuous; Stevens Type A35	ground elevation—395; in Moira River drainage area; on Moira River Conservation Authority property;gas in well
326*	Hu	II	1	drilled, rock	6	45	36 feet limestone	since Dec. 15, 1969	periodic measurements	ground elevation—529; in Moira River drainage area; on Hungerford Township property (road allowance)
327*	Th	VI	16	drilled, rock	6	184	150 feet limestone	since Dec. 15, 1969	periodic measurements	ground elevation—350; in Moira River drainage area; on Moira River Conservation Authority property; salty water, gas in well
328*	Th	VI	16	drilled, overburden	2	5	sand	since Dec. 15, 1969	periodic measurements	ground elevation—350; in Moira River drainage area; on Moira River Conservation Authority property

* Observation wells constructed during the investigation period; all other wells are abandoned domestic wells

APPENDIX B

Records of Water Wells from which Water Samples were Obtained for Chemical Analyses

ABBREVIATIONS USED

Blck	—Black
Bldr	—Boulder
Brwn	—Brown
Con	—Concession
Grnt	—Granite
Grvl	—Gravel
Hpan	—Hardpan
Lmsn	—Limestone
Msnd	—Medium sand
Prdg	—Previously dug
Prdr	—Previously drilled
Shle	—Shale
Stns	—Stones
Tpsl	—Topsoil
Whit	—White

Table 17. Records of Water Wells from which Water Samples were Obtained for Chemical Analyses

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
					HASTINGS COUNTY							
100	Belleville City			C. Clapper	3/64	6¼	19	5	3	10	Fresh	Tpsl 3; Lmsn 19 Water 12
123	Cashel	II	24	A. Gunter	8/62	6	37	12	1	37	Fresh	Tpsl Msnd 3; Brwn Grnt 37 Water 35
141	Deloro Village			Deloro Village	4/44	10	58	8	236	55	Fresh	Tpsl 1; Lmsn 16; Lmsn Grnt Shle 53; Lmsn Grnt 58 Water 58
204	Elzevir	I	14	School Area #3	5/53	6	120	58	–	120	Fresh	Tpsl Msnd 8; Grnt 120 Water 75
241	Elzevir	IV	16	W. Roushorn	2/61	6	103	40	3	103	Fresh	Tpsl Clay 15; Red Grnt 25; Grey Grnt 103 Water 99
248	Elzevir	VIII	1	J. May	6/56	6	90	36	5	56	Fresh	Msnd 8; Grnt 90 Water 60
253	Elzevir	IX	16	A. Hutchison	7/66	6	38	8	–	38	Fresh	Tpsl Msnd 6; Grey Grnt 38 Water 22
463	Frankford Village			O. Grundshoe	1/64	6	48	4	12	30	Fresh	Shle 4; Lmsn 48 Water 34, 42
512	Hungerford	I	10	C. Carney	5/67	6	148	40	–	148	Fresh	Clay 4; Hpan Grvl 26; Grey Lmsn 148 Water 70
516	Hungerford	I	17	W. Coulter	3/61	6	92	25	10	70	Fresh	Clay Bldr 12; Msnd Grvl 20; Grey Lmsn 92 Water 89

527	Hungerford	I	10	H. Longwell	10/60	6	48	24	10	45	Fresh	Prdg 21; Hpan 37; Grey Lmsn 48 Water 45
554	Hungerford	IV	1	R. Robinson	10/54	6	77	47	–	77	Salty	Tpsl 4; Lmsn 77 Water 72
577	Hungerford	IV	10	F. Preston	8/49	6	110	40	–	–	Fresh	Clay 36; Lmsn 110 Water 88
581	Hungerford	IV	25	School Area #9	9/54	6	55	30	1	55	Sulphur	Clay Bldr 21; Lmsn 55 Water 54
608	Hungerford	VI	33	G. Deshane	9/65	6	45	18	3	30	Fresh	Prdg 19; Grey Lmsn 45 Water 35
643	Hungerford	VIII	18	C. Courneya	6/61	6	22	8	2	15	Fresh	Brwn Clay 10; Hpan 12; Grnt 22 Water 20
651	Hungerford	IX	10	D. Sedore	10/61	6	109	20	1	109	Fresh	Grvl Bldr 19; Red Grnt 109 Water 90
657	Hungerford	IX	34	H. Gaffney	9/59	6	107	12	4	70	Fresh	Clay Tpsl 12; Blue Lmsn 102; Red Grnt 107 Water 95
694	Hungerford	XI	11	L. Merow	2/57	6	135	100	25	120	Salty	Grvl 12; Lmsn Shle 17; Red Grnt 106; Whit Grnt 130; Red Grnt 135; Water 128
717	Hungerford	XII	23	D. Turcotte	9/66	6	39	10	¼	Dry	Fresh	Clay 3; Blck Grnt 39 Water 20
724	Hungerford	XIII	12	F. Frost	9/63	6	55	25	4	Dry	Fresh	Tpsl Msnd 8; Grey Grnt 55 Water 50
760	Huntingdon	III	12	G. Thompson	12/59	6	45	20	2	Dry	Fresh	Grey Clay Stns 16; Grey Lmsn 45 Water 40
798	Huntingdon	VI	6	C. Mitz	5/62	6	330	110	6	300	Sulphur	Clay 15; Lmsn 255; Red Shle 270; Blue Grnt 330 Water 305, 328

Table 17 (continued)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
851	Huntingdon	X	18	F. Stein	2/61	6	56	36	20	30	Fresh	Csnd Bldr 30; Clay 45; Lmsn 56 Water 46
986	Madoc Village			Madoc Village	4/50	6	210	16	51	–	Fresh	Brwn Msnd 3; Bldr Grnt 20; Grnt 210 Water 30, 100, 150, 200
1034	Madoc	I	9	J. Atkinson	10/58	6	76	32	6	76	Fresh	Prdg 30; Red Shle 76 Water 72
1068	Madoc	IV	20	T. Evans	10/67	6	295	40	1	295	Fresh	Clay 15; Lmsn 30; Red Shle 62; Blue Grnt 295 Water 62, 210, 280
1081	Madoc	V	4	S. Lavender	10/55	6	100	8	14	100	Fresh	Clay 12; Blue Grnt 100 Water 97
1104	Madoc	V	28	W.F. Harris	8/60	6	40	8	30	30	Poor	Clay Stns 10; Red Grnt 40 Water 40
1163	Madoc	VII	16	S. Moorcraft	9/57	6	35	25	2	35	Fresh	Msnd Stns 12; Red Grnt 35 Water 25
1178	Madoc	IX	5	E. Sexsmith	5/67	6	44	20	6	24	Fresh	Clay 20; Red Grnt 44 Water 20, 35
1197	Madoc	XI	25	E. Graham	12/67	6	64	37	20	39	Fresh	Clay Shle 16; Grey Lmsn 30; Red Lmsn 62; Blue Grnt 64 Water 45

1492	Marmora	VI	6	W. Lavender	8/53	5	45	12	2	12	Fresh	Tpsl Clay Bldr 11; Lmsn 45 Water 30
1517	Marmora	VII	8	Marmora Feed Mills	9/63	6	76	24	3	40	Fresh	Clay Bldr 15; Grnt 76 Water 70
1538	Marmora	VIII	20	G.R. Brown	5/65	6	71	26	1	71	Fresh	Msnd Grvl 33; Red Grnt 71 Water 45
1546	Marmora	X	20	G. Fox	1/63	6	40	12	10	20	Fresh	Clay 4; Red Grnt 40 Water 35
1708	Rawdon	XII	8	H. Burns	8/67	8	89	43	2	89	Fresh	Clay Msnd 3; Lmsn 85; Red Shle 89 Water 59, 84
2362	Sidney	V	10	F. Trusdale	5/64	6	63	10	5	50	Fresh	Clay 14; Hpan 21; Fsnd 56; Grvl 63 Water 63
2370	Sidney	V	26	D. Ketcheson	11/55	6	33	6	8	6	Sulphur	Blck Tpsl 3; Clay 20; Clay Grvl 21; Blck Lmsn 33 Water 33
2375	Sidney	V	35	G. Bradshaw	2/70	6	26	8	5	22	Fresh	Tpsl 5; Clay Grvl 18; Grey Lmsn 26 Water 18
2405	Sidney	VI	20	C. Carr	10/62	6	52	10	16	25	Fresh	Clay 40; Msnd 45; Lmsn 52 Water 45
3035	Thurlow	III	16	S. Watson	5/64	6	186	100	1	186	Sulphur	Clay Bldr 35; Grvl 40; Grey Lmsn 186 Water 100
3118	Thurlow	IV	12	E. Wich	6/51	6	48	9	–	–	Fresh	Prdg 19; Hpan Clay 29; Lmsn 48 Water 29
3125	Thurlow	IV	22	B.H. Martin	6/51	6	104	25	–	–	Fresh	Hpan Stones 35; Lmsn 104 Water 104
3171	Thurlow	V	3	A. Fox	5/64	6	58	18	5	58	Salty	Clay Bldr 19; Grey Lmsn 58 Water 18

Table 17 (continued)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
3211	Thurlow	V	14	G. Chambers	10/64	6	180	66	1	180	Salty	Clay 8; Grvl Bldr 20; Lmsn 180 Water 178
3294	Thurlow	VI	20	J. Ervin	7/62	6	87	44	1	87	Sulphur	Brwn Clay Bldr 14; Grey Lmsn 50; Lmsn 87 Water 83
3303	Thurlow	VII	18	A. Tummon	10/65	8	85	15	10	40	Sulphur	Grey Clay 8, Grey Lmsn 85 Water 80
3314	Thurlow	VII	25	D. Seames	7/62	6	143	34	10	110	Salty	Clay 12; Lmsn 143 Water 143
3350	Thurlow	IX	4	S. Cooke	8/65	8	125	76	30	80	Fresh	Grey Clay 20; Sand Grvl 34; Coarse Grvl 50; Sand Grvl 70; Grvl with Clay 98; Blue Clay 114; Grvl 121; Grey Lmsn 125 Water 120
3369	Thurlow	IX	31	G. Bailey	5/66	6	48	20	5	48	Sulphur	Clay Bldr 9; Grey Lmsn 48 Water 35
3400	Tudor	V	32	C. Donaldson	5/50	5	35	10	–	–	Fresh	Till 3; Lmsn 32; Hematite 35 Water 32
3402	Tudor	XVII	5	B. Johnston	1/70	6	64	6	1	116	Fresh	Prdg 38; Lmsn 64 Water 62
3423	Tudor	HRW	21	J. Brintnell	10/57	6	86	20	10	20	Fresh	Sand 8; Hard Blue Rock 86 Water 85

3428	Tweed Village			Tweed Village	6/54	10	435	81	165	140	Fresh	Sand 41, Red Grnt 435 Water 428
3565	Tyendinaga	V	16	R.C. Rectory	7/67	6	166	100	10	120	Salty	Grvl Bldrs 7; Lmsn Shle 19; Hard Grey Lmsn 157; Soft Green Lmsn 162; Hard Grey Lmsn 166 Water 160
3575	Tyendinaga	V	10	H. Slot	10/60	6	185	60	10	100	Fresh	Clay 10; Lmsn 130; Whit Quartz 150; Brwn Rock 160; Whit Quartz 170; Red Grnt 185 Water 172
3628	Tyendinaga	VII	24	A. Gaffney	2/67	30	35	31	4	32	Fresh	Prdg 12; Soft Lmsn 35 Water 32
4367	Thurlow	VI	22	Ontario Ministry of the Environment	12/69	6	190	22	2	49	Salty	Brwn Tpsl 1; Brwn Clay Bldr 3; Brwn Clay Grvl Bldr 45; Brwn Lmsn 188; Red Grnt 190 Water?
4369	Thurlow	VI	22	Ontario Ministry of the Environment	11/69	6	185	–	–	–	Salty	Brwn Tpsl 1; Sand Grvl 21; Grey Clay 23; Brwn Sand 29; Brwn Lmsn 179; Red Grnt 185 Water?
4370	Hungerford	II	1	Ontario Ministry of the Environment	11/69	2	195	–	–	–	Salty	Tpsl 2; Brwn Lmsn 185; Red Grnt 195 Water?
4371	Hungerford	II	1	Ontario Ministry of the Environment	10/69	6	45	18	2	21	Fresh	Brwn Tpsl 1; Brwn Clay Bldr 9; Brwn Lmsn 45 Water?

Table 17 (continued)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
					LENNOX AND ADDINGTON COUNTY							
157	Anglesea	XI	5	G. Pearson	7/66	5	71	5	1	65	Fresh	Sand Bldr 26; Hard Blck Grnt 60; Snds 71 Water 64
1349	Kaladar	IV	22	D. Davison	10/59	2	53	11	4	25	Fresh	Sand 8; Lmsn 53 Water 58
1355	Kaladar	VII	10	Dept. Public Works	8/56	6	94	Flw	10	0	Fresh	Tpsl 3; Clay 12; Grey Grnt 94 Water 70
2209	Richmond	XI	2	H. York	11/64	6	26	14	10	14	Fresh	Prdg 14; Hard Grey Lmsn 26 Water 18
2231	Sheffield	II	18	J. Gaffney	10/50	6	54	22	6	–	Fresh	Grvl 6; Lmsn 39; Grnt 54 Water 39
2304	Sheffield	V	18	J. Grath	10/65	6	236	50	2½	220	Fresh	Shle 6; Lmsn 70; Grnt 236 Water 225

APPENDIX C

Water Quality Analyses

Figures 30-35 inclusive indicate the spatial distribution in the basin of chemical parameters commonly used to assess the suitability of waters for domestic use. The permissible criteria (Ontario Ministry of the Environment, 1974) for these parameters are listed below:

Chemical Parameter	Permissible Criteria(ppm)
Nitrate (NO_3)	45
Total Iron	0.3
Chloride	250
Sulphate	250
Total Dissolved Solids (TDS)	500

In addition, hardness of waters is classed as follows:

Hardness (ppm $CaCO_3$)	Class
<60	soft
61-120	moderately hard
121-180	hard
>180	very hard

Whenever possible, waters with concentrations in excess of the permissible criteria should be limited in use.

Table 18. Chemical Analyses of Lake and Rainwater Samples
(Locations of sampling points are shown on Figure 24)

Location	Depth	Date Sampled	pH	Ionic Concentrations (ppm)												Total Alkalinity as $CaCO_3$ (ppm)	Total Hardness as $CaCO_3$ (ppm)	Total Dissolved Solids (ppm)	Specific Conductance (mmhos/cm at 25°C)
				Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate	Arsenic	Silica				
Dry Lake 1	surface	13/8/69	8.2	55	5	2	0.9	169	18	4	0.10	0.1	0.04	0	5.4	140	159	200	302
Wolf Lake 2	surface	13/8/69	7.5	22	2	1	0.9	67	9	1	0.30	0.1	0.04	0	2.2	55	62	120	126
Jarvis Lake 3	surface	13/8/69	7.8	50	2	2	0.7	151	14	1	0.25	0.3	0.04	<0.01	12.9	125	136	210	250
Merrill Lake 4	surface	12/8/69	6.0	5	1	1	0.7	12	13	1	1.05	0.1	0.13	0.02	3.8	10	21	40	41
Deerock Lake 5	surface	12/8/69	6.9	7	1	1	0.6	16	13	1	0.60	0.1	0.04	0.02	1.8	13	24	40	44
Bay of Quinte 6	surface	14/8/69	8.5	42	4	4	1.1	110	17	6	0.30	0.2	0.04	0.024	0.8	109	123	150	243
Stoco Lake 7	surface	14/8/69	7.9	34	4	3	1.1	110	13	3	0.15	—	0.04	0.07	3.5	91	102	150	206
Stoco Lake 7	35 feet	14/8/69	7.0	29	5	2	1.2	95	13	3	1.45	—	0.04	0.26	5.5	78	90	150	195
Stoco Lake 8	surface	14/8/69	8.4	34	5	1	1.1	101	15	3	0.2	—	0.04	0.07	3.2	91	104	150	206
Stoco Lake 8	20 feet	14/8/69	7.4	35	4	3	1.0	113	15	3	0.35	—	0.04	0.09	4.4	93	106	150	209
Stoco Lake 9	surface	13/8/69	7.7	34	4	3	1.1	109	15	3	0.25	0.1	0.04	0.07	3.7	90	102	150	207
Mellon Lake 10	surface	12/8/69	7.5	10	1	3	0.9	28	11	2	0.05	0.1	0.04	0	0.6	23	30	45	75
Mellon Lake 10	30 feet	12/8/69	6.9	10	2	3	0.9	30	10	1	0.10	—	9.7	<0.01	2.7	25	33	50	67

Mellon Lake 11	surface	12/8/69	7.6	10	1	2	0.9	29	11	1	0.05	—	0.04	<0.01	0.7	24	30	50	61
Mellon Lake 11	30 feet	12/8/69	6.8	10	2	2	0.9	30	10	2	0.05	—	0.93	0.016	2.8	25	32	40	66
Mellon Lake 11	60 feet	12/8/69	6.8	10	1	1	0.9	29	12	1	0.1	0.1	0.93	0.016	3.4	24	32	40	72
Mellon Lake 11	90 feet	12/8/69	6.6	10	1	2	0.9	30	13	1	0.20	—	0.93	<0.01	4.0	25	32	50	52
Skootamatta Lake 12	surface	12/8/69	7.2	7	1	1	0.9	20	16	1	0.10	—	0.04	<0.01	0.9	16	25	50	53
Skootamatta Lake 12	30 feet	12/8/69	6.5	8	1	1	0.8	15	16	1	0.10	—	0.58	0	2.0	12	24	50	53
Skootamatta Lake 12	60 feet	12/8/69	6.4	8	1	1	0.8	15	15	1	0.10	0.1	0.66	0.016	2.0	12	25	40	52
Skootamatta Lake 12	90 feet	12/8/69	6.4	8	1	1	0.8	16	15	1	0.2	—	0.75	<0.01	2.3	13	24	30	53
Skootamatta Lake 13	surface	12/8/69	7.0	8	1	1	0.9	16	14	1	0.20	—	0.04	<0.01	0.8	13	24	40	54
Skootamatta Lake 13	30 feet	12/8/69	6.6	8	1	1	1.0	15	14	1	0.10	0.1	0.35	<0.01	2.2	12	25	40	55
Skootamatta Lake 13	60 feet	12/8/69	6.4	8	1	1	0.9	16	15	1	0.15	—	0.75	<0.01	2.6	13	25	50	55
Skootamatta Lake 13	90 feet	12/8/69	6.4	8	1	1	0.9	16	17	1	0.8	—	0.84	<0.01	2.7	13	25	40	53
Moira Lake 14	surface	12/8/69	8.4	48	5	4	1.3	121	17	5	0.10	0.1	0.04	0.14	4.6	123	140	140	264
Moira Lake 14	25 feet	12/8/69	7.6	48	5	4	1.4	156	17	5	0.10	—	0.04	0.18	5.6	129	141	170	278
Moira Lake 15	surface	12/8/69	8.2	58	4	6	1.6	167	26	7	0.10	—	0.04	0.40	5.4	138	160	210	314
Moira Lake 15	20 feet	12/8/69	7.4	56	8	4	1.8	189	19	6	0.6	0.1	0.04	0.25	8.1	156	171	210	331
Rainwater (Tweed)		21/10/69	7.5	4	1	0.4	0.3	—	6	1	0.15	0	—	—	—	12	13	—	28

Table 19. Chemical Analyses of Stream-Water Samples (Locations of sampling points are shown on Figure 23)

Sample Number	Location	Date Sampled	pH	Ionic Concentrations (ppm) Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate	Arsenic	Silica	Total Alkalinity as $CaCO_3$(ppm)	Total Hardness as $CaCO_3$(ppm)	Total Dissolved Solids (ppm)	Specific Conductance (mmhos/cm at 25°C)
1	Moira River	11/8/69	8.0	42	5	2	1.0	134	13	5	0.1	—	0.04	0.05	4.2	110	124	170	261
2	Parks Creek	11/8/69	8.3	76	6	2	1.0	247	21	4	0.05	0.3	0.04	<0.01	9.0	203	219	260	388
3	Moira River	11/8/69	8.2	36	5	3	1.0	116	20	4	0.35	—	0.04	0.05	3.8	95	110	140	221
4	Parks Creek	11/8/69	7.5	61	6	2	1.1	190	23	7	0.05	—	0.04	0	3.8	156	178	210	335
5	Moira River	11/8/69	7.9	34	5	3	1.1	110	19	4	0.15	—	0.04	0.06	3.7	90	105	140	206
6	Clare River	11/8/69	7.5	69	9	2	0.8	239	17	3	0.05	0.3	0.04	0.02	10.4	196	211	230	375
7	Goose Creek	11/8/69	7.8	86	8	2	0.9	288	19	2	0.15	0.1	0.04	0.016	9.6	236	252	300	441
8	Clare River	11/8/69	8.1	46	9	2	0.6	171	17	4	0.05	—	0.04	<0.01	4.3	140	153	180	281
9	Moira River	11/8/69	8.4	46	5	3	1.2	135	22	4	0.15	—	0.04	0.68	4.9	117	136	180	259
10	Moira River	11/8/69	7.9	46	5	2	1.2	145	18	3	1.10	—	0.22	0.05	4.6	119	132	160	254
11	Moira River	11/8/69	8.0	51	6	3	1.3	166	20	5	0.15	0.2	1.11	0.016	4.5	136	154	210	293
12	Moira River	11/8/69	7.6	35	3	1	0.9	107	15	1	0.20	—	0.04	<0.01	4.9	88	99	150	187
13	Jordan River	11/8/69	7.6	46	3	4	1.7	143	16	5	0.35	0.1	0.22	<0.01	3.6	117	129	170	251
14	Moira River	11/8/69	7.7	37	3	1.8	0.9	115	7	3	0.15	—	0.13	<0.01	3.9	94	104	140	203
15	Madoc Cr.	11/8/69	8.2	83	19	4	1.7	322	25	6	0.1	0.3	1.81	0	3.1	264	288	310	492
16	Madoc Cr.	11/8/69	8.2	80	13	5	2.0	290	23	8	0.10	—	0.88	<0.01	3.7	238	255	330	467
17	Moira River	11/8/69	8.3	56	6	14	1.7	167	38	11	0.05	0.5	0.04	0.39	6.7	137	165	240	364

18	Moira River	11/8/69	8.4	47	5	4	1.4	149	21	5	0.15	—	0.04	0.14	5.7	122	122	190	277
19	Black River	12/8/69	7.7	15	3	1	1.1	51	9	2	0.35	0.1	0.22	<0.01	2.4	42	52	70	110
20	Skootamatta River	12/8/69	7.5	12	3	1	0.9	38	9	2	0.4	0.1	0.04	<0.01	2.7	31	40	50	84
21	Skootamatta River	12/8/69	7.4	13	2	2	0.9	41	13	3	0.8	—	0.04	<0.01	1.8	34	42	90	96
22	Moira River	12/8/69	7.8	33	4	3	1.1	104	13	3	0.25	—	0.71	0.06	5.0	85	98	120	196
23	Skootamatta River	12/8/69	7.4	8	1	1	0.8	17	13	1	0.2	—	0.04	<0.01	1.9	17	24	35	54
24	Skootamatta River	12/8/69	7.1	8	1	1	0.8	18	12	1	0.40	—	0.04	0	1.8	15	24	30	50
25	Skootamatta River	13/8/69	7.2	6	3	1	0.8	21	12	2	0.80	0.4	0.04	0	1.6	16	26	40	52
26	Sulphide Cr.	13/8/69	7.1	34	6	4	1.1	94	30	5	1.85	0.3	0.75	<0.01	7.4	77	108	160	228
27	Otter Cr.	13/8/69	7.8	40	8	3	1.4	155	11	4	0.2	0.2	0.04	<0.01	5.8	127	135	170	261
28	Tributary of Otter Creek	13/8/69	7.1	7	7	2	0.7	54	12	2	0.80	—	0.13	0	2.3	44	48	80	107

Table 20. Chemical Analyses of Ground-Water Samples
(Locations of sampling points are shown on Figure 24)

Well Number	Location	Date Sampled	pH	Ionic Concentrations (ppm) Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate	Arsenic	Silica	Total Alkalinity as $CaCO_3$(ppm)	Total Hardness as $CaCO_3$(ppm)	Total Dissolved Solids (ppm)	Specific Conductance (mmhos/cm at 25°C)
100	Belleville	13/8/69	7.1	149	13	76	7.1	464	96	92	0.65	0	1.37	0	9.4	338	427	740	1070
123	Cashel Twp. II-24	13/8/69	7.1	48	6	49	6.8	215	32	16	0.1	0.1	22.1	<0.01	7.9	176	143	330	492
141	Deloro Village	28/5/69	7.4	—	—	—	—	—	—	12	0.05	—	—	—	—	267	323	—	—
157	Anglesea Twp. XI-5	13/8/69	8.0	28	6	2	2.6	91	21	2	0.2	0.2	0.09	0	8.8	75	93	120	198
204	Elzevir Twp. I-14	13/8/69	7.8	50	12	10	3.3	200	26	6	0.35	0.3	0.27	0.016	10.7	164	173	230	379
241	Elzevir Twp. IV-16	13/8/69	7.3	96	8	9	5.3	338	24	8	0.10	0	48.7	<0.01	7.9	277	327	280	628
248	Elzevir Twp. VIII-1	13/8/69	7.3	86	18	17	4.4	284	43	28	0.10	0.1	2.17	0	10.9	233	289	380	582
253	Elzevir Twp.	13/8/69	6.7	30	4	4	2.5	80	22	4	0.10	0.4	7.08	0	11.2	66	90	125	199
463	Frankford	13/8/69	6.5	98	23	20	6.5	272	22	101	1.05	0.1	0.04	<0.01	12.7	223	340	550	762
512	Hungerford Twp. I-10	13/8/69	7.6	45	17	230	6.9	341	116	196	0.20	0.5	0.53	<0.01	8.5	280	181	800	1370
516	Hungerford Twp. I-17	13/8/69	7.4	94	12	10	1.3	258	30	26	0.10	0	26.6	<0.01	7.8	212	282	360	582
527	Hungerford Twp. I-10	13/8/69	7.4	114	17	40	2.1	378	43	49	0.05	0	18.1	0	9.4	310	357	550	835
554	Hungerford Twp. IV-1	13/8/69	7.2	124	8	5	1.6	296	36	45	0.3	0	2.61	0	9.9	243	345	480	678
577	Hungerford Twp. IV-10	13/8/69	7.1	114	12	10	16	330	44	10	0.10	0	48.7	<0.01	9.9	271	332	420	680

581	Hungerford Twp. IV-25	13/8/69	7.2	91	18	4	1.8	341	18	5	0.05	0	10.6	0.015	7.1	280	307	360	578
608	Hungerford Twp. VI-33	13/8/69	7.2	252	37	12	4.2	272	540	4	1.75	0.7	0.22	<0.01	9.8	223	786	1140	1270
643	Hungerford Twp. VIII-18	13/8/69	7.4	93	7	4	1.6	299	14	3	0.15	0	2.21	0	10.1	245	262	280	508
651	Hungerford Twp. IX-10	13/8/69	7.3	91	14	8	2.1	—	34	8	0.10	1.2	15.9	<0.01	13.8	295	286	340	561
657	Hungerford Twp. IX-34	13/8/69	7.0	143	19	8	2.8	369	81	31	0.05	0	16.4	0.015	10.3	303	436	570	819
694	Hungerford Twp. XI-11	13/8/69	7.2	210	22	24	6.5	322	320	16	0.10	0	30.1	0	8.0	264	616	900	1110
717	Hungerford Twp. XII-23	13/8/69	7.2	278	36	41	4.5	240	560	95	2.15	0.5	0.22	0	15.6	197	848	1390	1520
724	Hungerford Twp. XIII-12	13/8/69	6.0	16	4	8	0.9	39	26	10	0.65	0.1	1.77	0	9.9	32	56	100	177
760	Huntingdon Twp. III-12	13/8/69	7.0	139	9	4	4.4	406	27	4	0.30	0	18.6	0	11.4	333	385	440	704
798	Huntingdon Twp. VI-6	12/8/69	7.4	138	9	25	4.5	324	46	30	0.05	0	88.5	<0.01	9.4	266	384	620	835
851	Huntingdon Twp. X-18	12/8/69	7.2	124	9	8	0.8	290	22	58	0.5	0	30.1	<0.01	11.6	238	349	530	693
986	Madoc Village	1/3/72	—	128	25	32	4.3	—	50	67	—	—	15.05	—	—	330	424	—	—
1034	Madoc Twp. I-9	14/8/69	7.3	90	2	2	1.0	254	23	2	0.20	0.1	0.75	0	8.2	208	231	260	429
1068	Madoc Twp. IV-20	13/8/69	7.2	106	26	11	43	427	34	14	0.65	0.1	42.5	0	7.6	350	373	500	783
1081	Madoc Twp. V-4	13/8/69	7.0	171	86	50	3.7	546	112	237	0.3	0.3	0.66	<0.01	26.6	448	787	1190	1550
1104	Madoc Twp. V-28	13/8/69	6.9	79	6	—	8.8	216	57	126	0.10	0.2	4.4	<0.01	6.7	177	220	520	853
1163	Madoc Twp. VII-16	13/8/69	7.4	90	5	2	1.0	263	25	2	0.10	0.1	1.15	0.016	5.2	216	244	260	450

Table 20 (continued)

Well Number	Location	Date Sampled	pH	Ionic Concentrations (ppm) Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate	Arsenic	Silica	Total Alkalinity as $CaCO_3$(ppm)	Total Hardness as $CaCO_3$(ppm)	Total Dissolved Solids (ppm)	Specific Conductance (mmhos/cm at 25°C)
1178	Madoc Twp. IX-5	14/8/69	7.3	96	22	6	4.1	346	32	9	0.1	0	23.5	0	11.2	284	332	400	622
1197	Madoc Twp. XI-25	14/8/69	7.2	101	27	5	1.9	369	20	8	0.1	0	38.5	<0.01	7.1	303	364	420	660
1349	Kaladar Twp. IV-22	13/8/69	7.4	65	6	12	3.4	173	50	13	0.2	0.2	0.84	<0.01	12.0	142	185	260	409
1355	Marmora Twp. VII-10	13/8/69	7.8	35	8	23	4.2	154	40	6	0.10	0.9	0.18	0	10.4	126	126	210	343
1492	Marmora Twp. VI-6	14/8/69	7.3	86	20	75	4.7	361	98	43	0.10	0.4	8.8	<0.01	11.6	296	301	570	856
1517	Marmora Twp. VII-8	14/9/69	7.0	123	11	13	1.3	368	40	19	0.10	0.1	14.2	0	12.4	302	354	430	687
1538	Marmora Twp. VIII-20	14/9/69	7.3	60	24	15	6.1	317	8	10	1.4	1.4	0.13	<0.01	13.6	260	250	300	506
1546	Marmora Twp. X-20	14/9/69	7.0	118	25	18	31	433	40	42	0.10	0	17.7	<0.01	11.8	355	398	550	853
1708	Rawdon Twp. XII-8	14/9/69	7.4	84	15	82	8.1	323	70	100	0.1	0.5	3.1	<0.01	8.1	265	273	570	923
2209	Richmond Twp. XI-2	14/9/69	7.1	110	11	4	10	345	22	6	0.05	0	23.5	0	8.0	283	319	390	620
2231	Sheffield Twp. II-18	14/9/69	7.3	86	17	3	1.9	312	19	3	0.05	0	6.2	0.02	6.9	256	284	300	522
2304	Sheffield Twp. V-18	14/9/69	7.4	86	35	5	3.2	374	52	3	0.05	0.1	11.5	0	7.0	307	362	420	678

2362	Sidney Twp. V-10	12/8/69	7.5	68	15	7	1.8	267	15	2	1.05	0.3	0.04	<0.01	14.3	219	230	250	448
2370	Sidney Twp. V-26	12/8/69	7.1	146	18	13	10	394	54	30	0.05	0	57.5	0	15.1	323	442	630	872
2375	Sidney Twp. V-35	12/8/69	7.2	159	26	44	19	417	112	69	1.0	0	106	0	14.3	342	506	890	930
2405	Sidney Twp. VI-20	12/8/69	7.7	57	14	6	1.8	197	17	6	0.10	0	39.8	0	14.2	162	200	290	390
3035	Thurlow Twp. III-16	12/8/69	7.1	102	59	36	104	485	141	73	0.05	0.3	68.6	0.024	13.3	398	468	840	1270
3118	Thurlow Twp. IV-12	13/8/69	6.9	192	24	36	2.1	407	116	84	0.05	0	119.5	<0.01	18.1	334	580	910	1210
3125	Thurlow Twp. IV-22	13/8/69	6.9	120	48	16	6.4	410	91	58	0.05	0	14.2	<0.01	22.2	336	498	660	925
3171	Thurlow Twp. V-3	13/8/69	7.3	324	53	560	9.9	236	350	1233	0.15	0.4	—	—	—	194	1030	—	4320
3211	Thurlow Twp. V-14	13/8/69	7.4	132	13	11	1.0	297	38	58	0.05	0	—	—	—	244	385	—	783
3294	Thurlow Twp. VI-20	13/8/69	7.0	136	24	10	3.6	380	73	34	0.05	0	—	—	—	312	438	—	825
3303	Thurlow Twp. VII-18	12/8/69	7.2	96	36	85	3.4	423	82	96	1.60	0.1	0.09	0	12.1	347	392	650	1070
3314	Thurlow Twp. VII-25	12/8/69	7.2	158	11	50	1.2	339	27	139	0.05	0	6.2	<0.01	8.6	278	440	880	1080
3350	Thurlow Twp. IX-4	13/8/69	7.4	76	20	4	1.5	312	11	4	0.10	0	2.61	0	17.5	256	274	300	512
3369	Thurlow Twp. IX-31	12/8/69	6.9	176	9	136	3.5	464	30	248	1.8	0.4	0.09	<0.01	10.7	381	476	920	1460
3400	Tudor Twp. V-32	12/8/69	7.0	112	7	10	12.4	319	47	11	0.30	0.2	19.5	0	9.3	262	311	410	633
3402	Tudor Twp. XVII-5	13/8/69	7.4	118	21	84	3.1	315	114	59	0.15	0	106	0	12.9	258	382	750	1060

Table 20 (continued)

Well Number	Location	Date Sampled	pH	Ionic Concentrations (ppm)												Total Alkalinity as $CaCO_3$(ppm)	Total Hardness as $CaCO_3$(ppm)	Total Dissolved Solids (ppm)	Specific Conductance (mmhos/cm at 25°C)
				Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate	Arsenic	Silica				
3423	Tudor Twp. HRW-21	13/8/69	7.3	82	9	5	3.9	256	35	8	0.10	0.1	0.89	0	8.5	210	247	300	466
3428	Tweed Village	24/4/68	7.7	—	—	—	—	—	51	10	0.12	—	2.08	—	—	222	278	—	—
3430	Tweed Village	1/8/69	7.7	—	—	—	—	—	38	25	0.05	—	2.77	—	—	242	280	—	—
3565	Tyendinaga Twp. V-16	14/8/69	7.1	94	20	8	9.8	362	23	14	2.5	0.3	21.2	0	5.3	297	318	440	672
3575	Tyendinaga Twp. V-10	14/8/69	7.1	135	18	65	49	356	149	110	0.05	0.1	14.2	0	7.2	292	414	790	1170
3228	Tyendinaga Twp. VII-24	14/8/69	7.5	91	12	4	1.9	278	32	8	0.15	0	23.0	0	5.4	228	276	350	562
4367	Thurlow Twp. VI-24	24/2/72	—	1160	413	1325	18	242	320	—	13	—	0.01	—	—	200	4600	—	—
4369	Thurlow Twp. VI-13	22/7/70	7.3	296	50	11,250	60	264	630	19,460	37.3	1.9	0.01	0.06	9.0	217	950	2140	3060
4370 (sample from 55 feet)	Hungerford Twp. II-1	22/7/70	12.7	264	158	291	548	—	0	1945	15	—	0.03	0.01	1.4	3080	1320	4130	12,800
4370 (sample from 165 feet)	Hungerford Twp. II-1	22/7/70	11.8	16	1	513	435	—	26	836	16.3	1.0	0.31	0.05	17.0	497	44	2460	4510
4371	Hungerford Twp. II-1 (same as 4370)	22/7/70	7.6	32	30	82	5.7	—	11	51	1.25	0.9	0.02	0.01	11.0	280	204	470	698

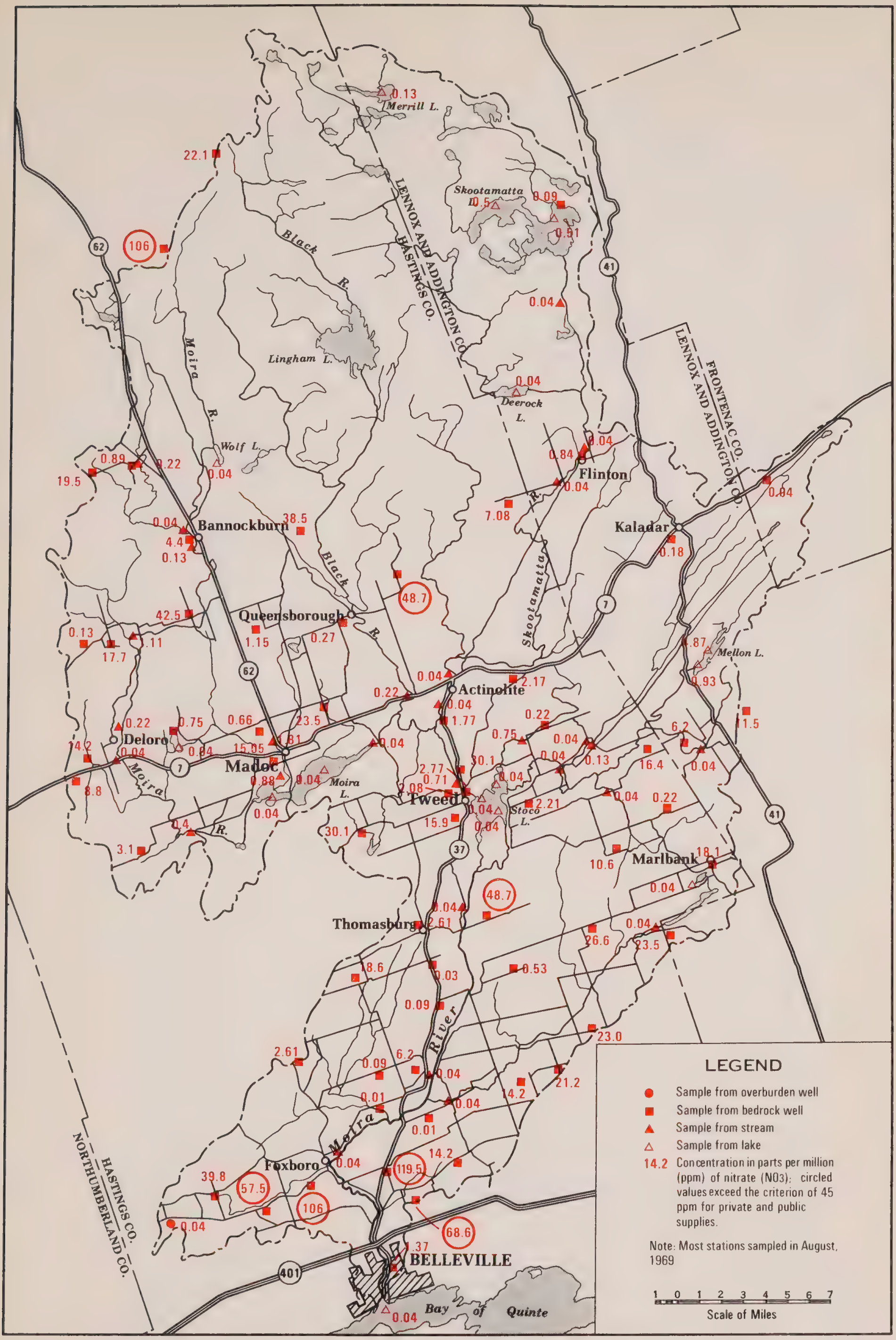


Figure 30. Concentration of nitrate (NO_3) in surface- and ground-water samples in the Moira River basin.

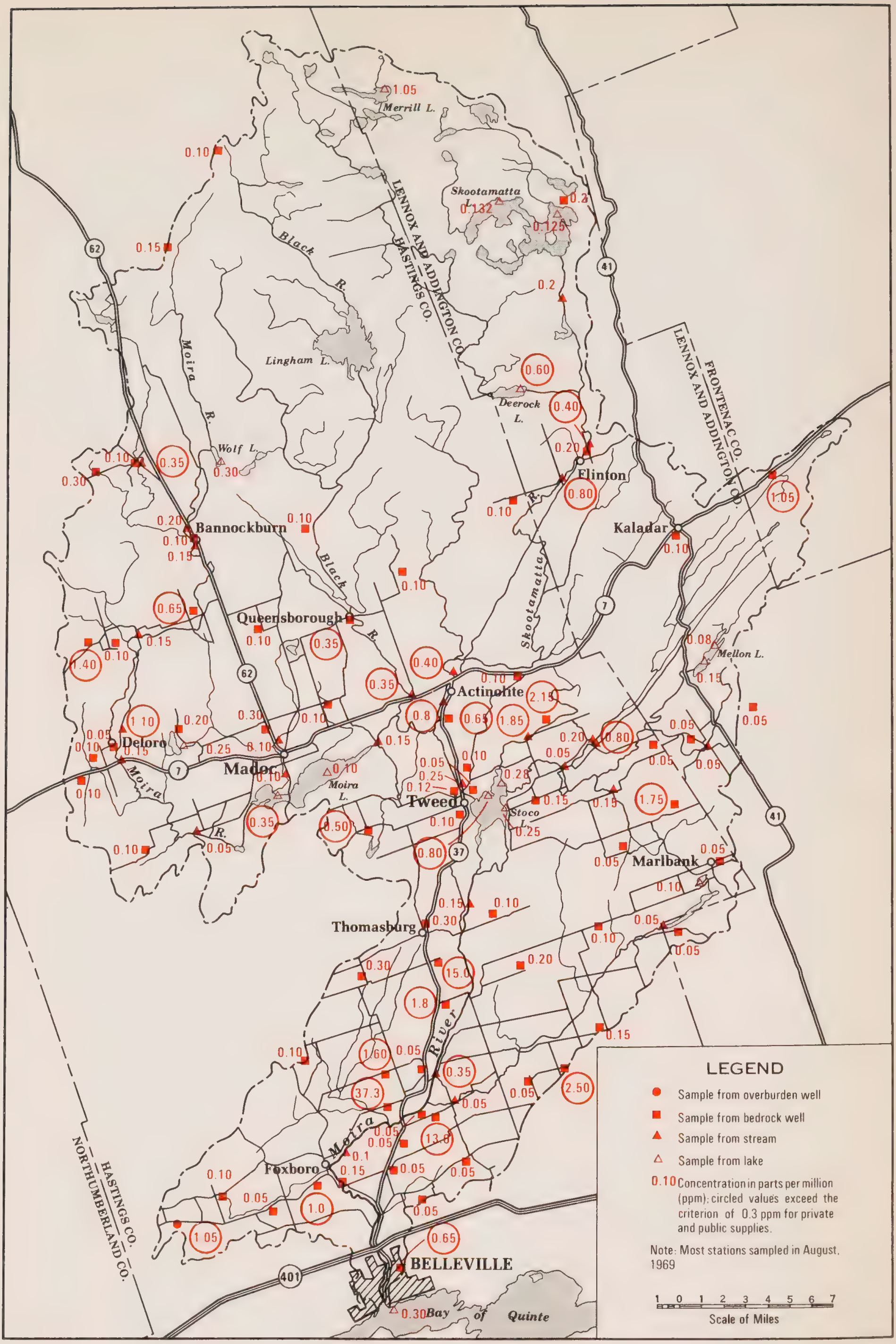


Figure 31. Concentration of total iron in surface- and ground-water samples in the Moira River basin.

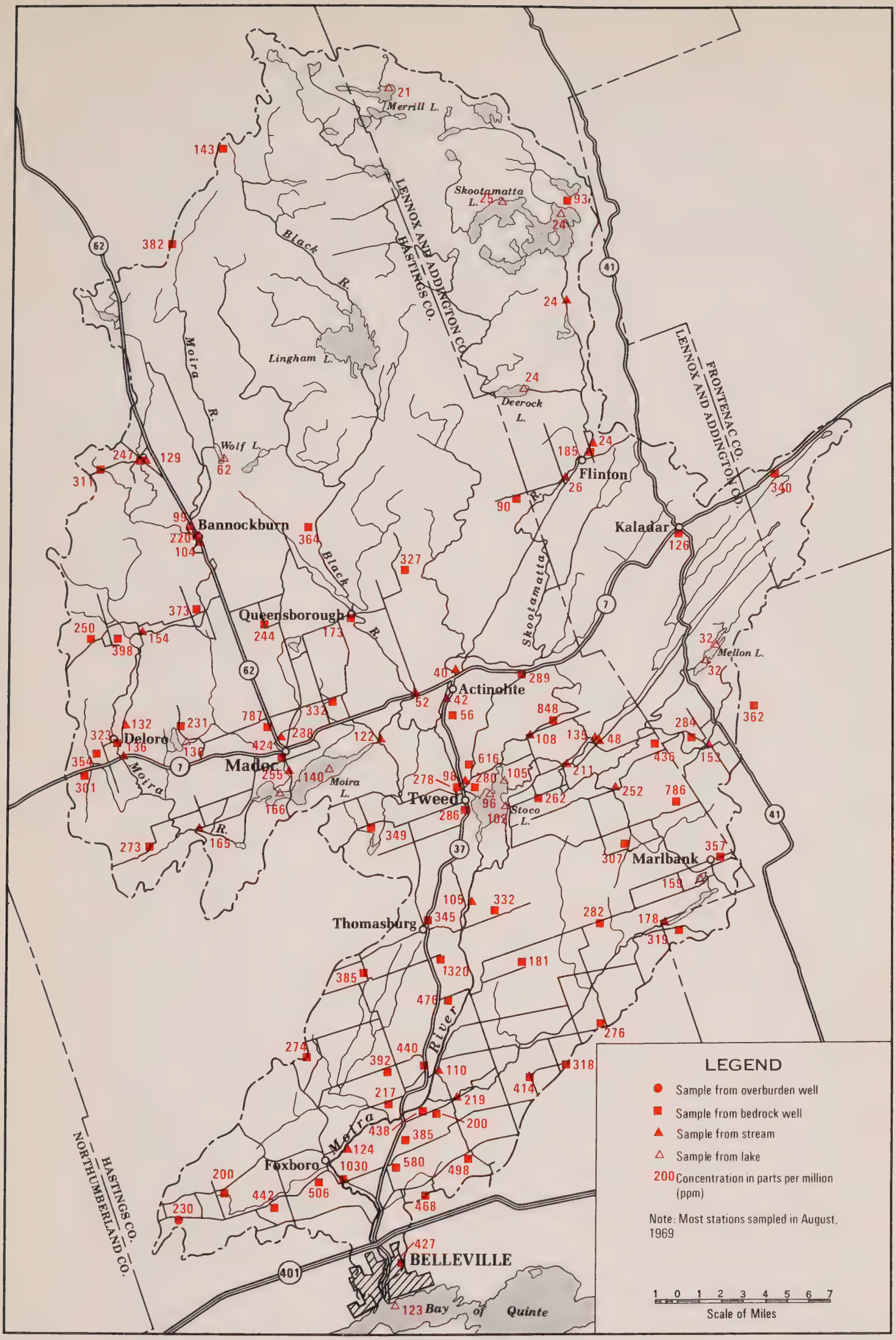


Figure 32. Total hardness of water in surface- and ground-water samples in the Moira River basin.

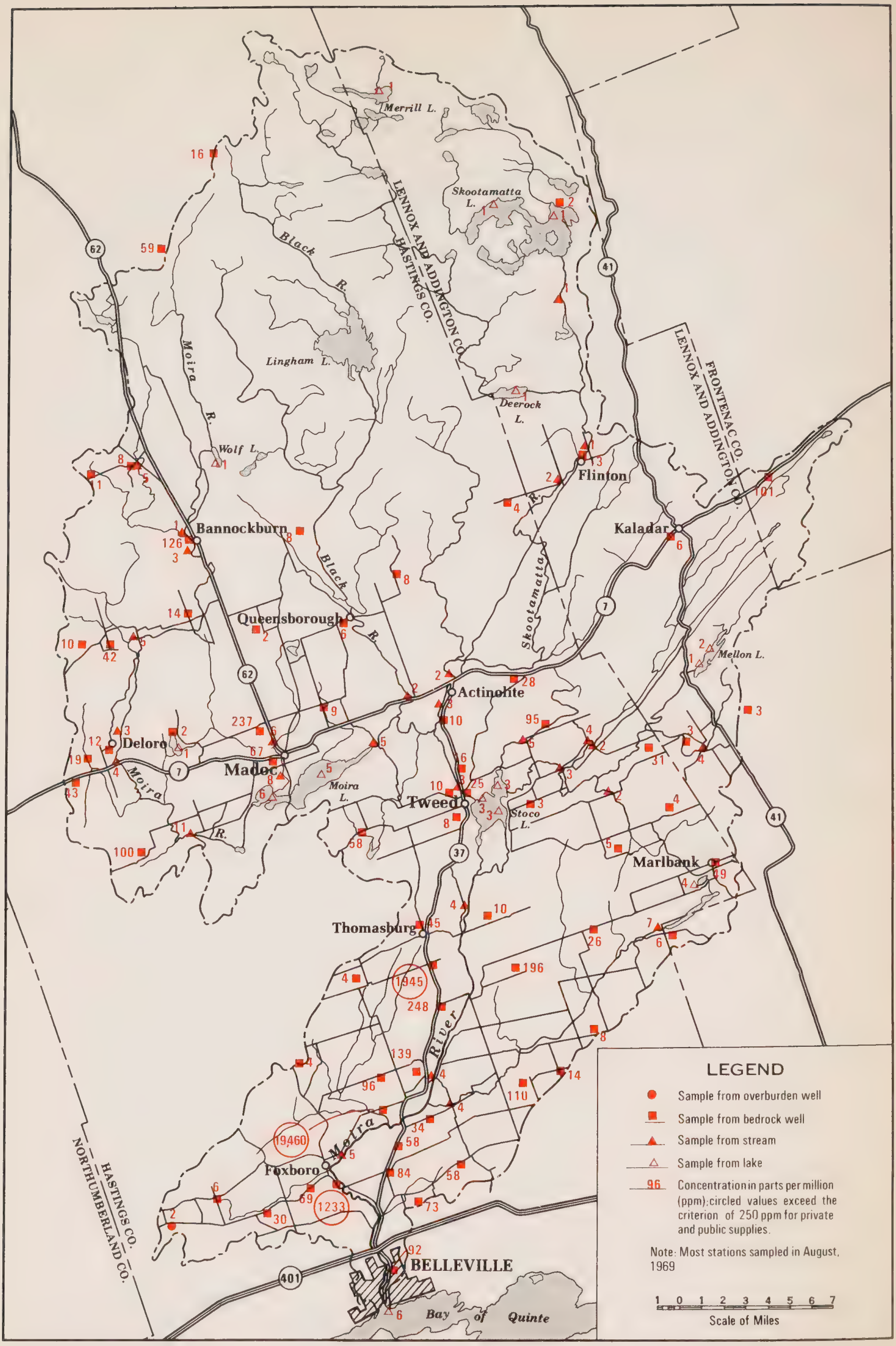


Figure 33. Concentration of chloride in surface- and ground-water samples in the Moira River basin.

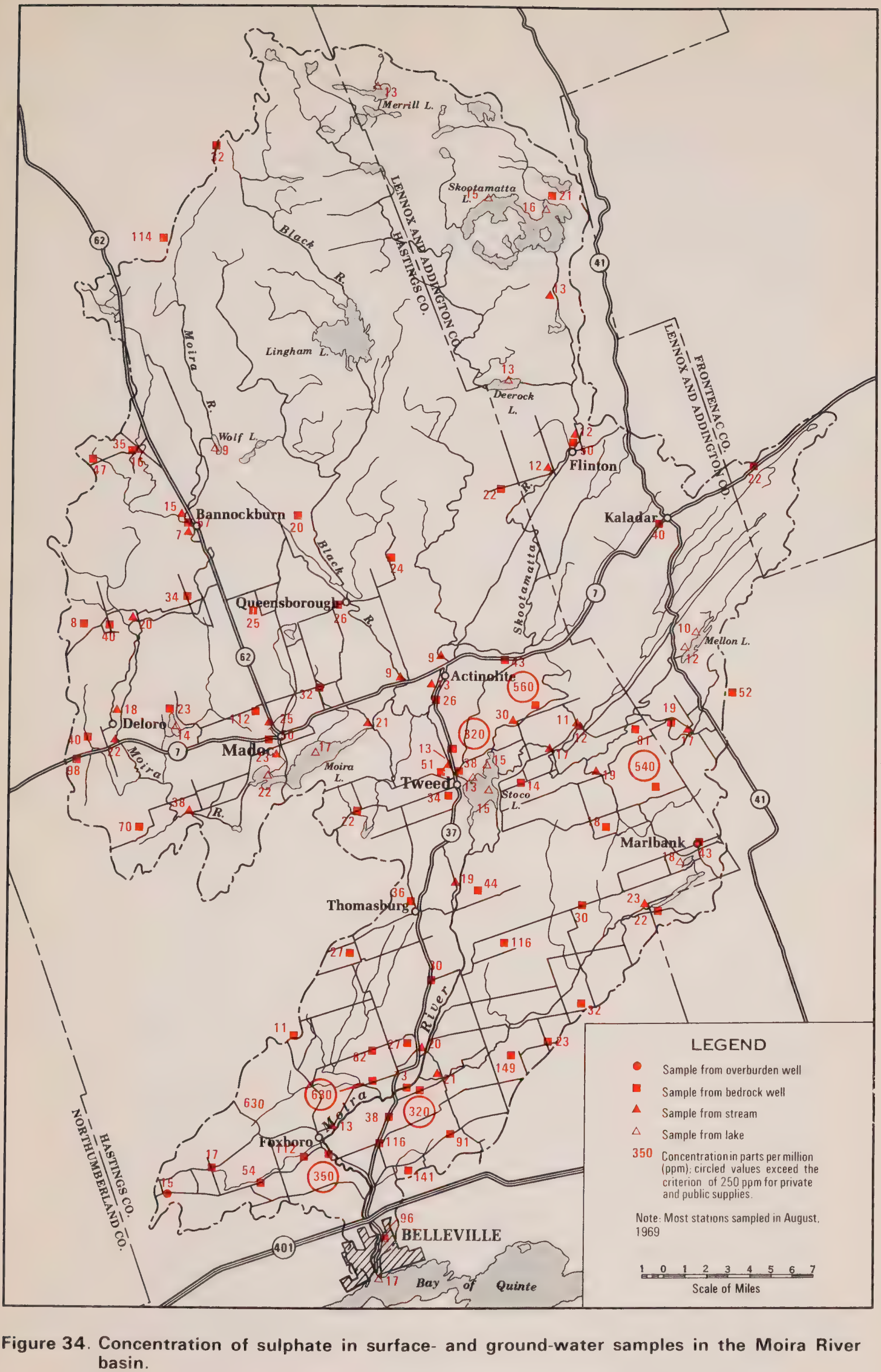


Figure 34. Concentration of sulphate in surface- and ground-water samples in the Moira River basin.

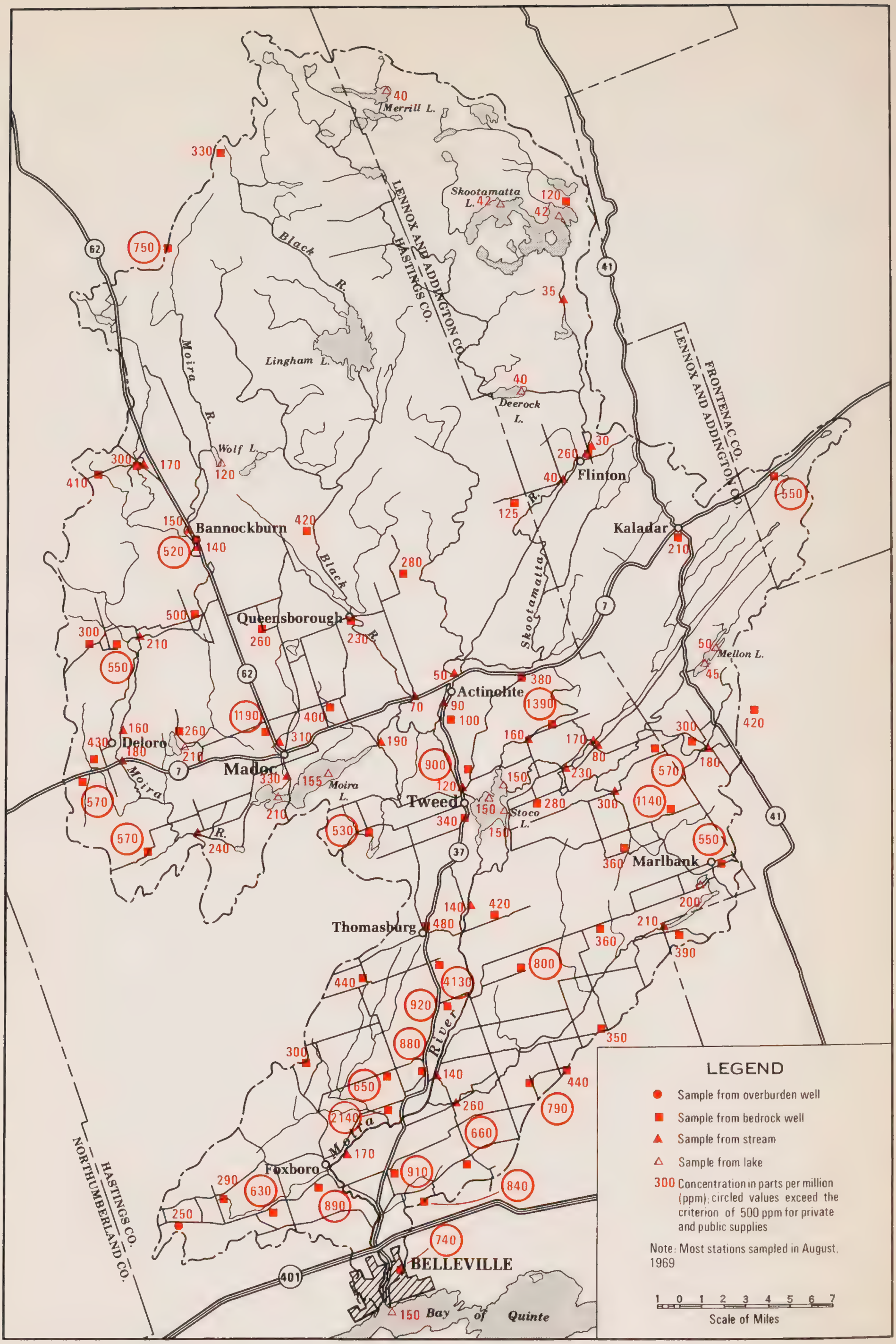


Figure 35. Concentration of total dissolved solids in surface- and ground-water samples in the Moira River basin.

APPENDIX D

Streamflow Data

Table 21. Variation of Monthly Discharges at Gauging Station 02HL001 on the Moira River near Foxboro (1916-1969 data)

Month	Discharge in cubic feet per second (cfs)				
	Maximum	Mean	Median	Minimum	Range
January	3700	818	649	38	3662
February	2190	664	544	38	2152
March	5120	1930	1880	98	5022
April	7650	4050	3920	1450	6200
May	5520	1880	1620	540	4980
June	3790	832	604	130	3660
July	1150	311	234	70	1080
August	1360	168	120	44	1316
September	550	117	96	30	520
October	2640	285	114	28	2612
November	2920	639	315	40	2880
December	3040	839	725	37	3003
Year	1940	1040	1030	522	1418

Table 22. Variation of Monthly Discharges at Gauging Station 02HL003 on the Black River (1956-1969 data)

Month	Discharge in cubic feet per second (cfs)				
	Maximum	Mean	Median	Minimum	Range
January	183	98.8	92.8	6.6	176.4
February	192	97.1	95.0	8.8	183.2
March	438	211	183	73	365
April	1240	544	464	234	1006
May	653	275	230	126	527
June	262	104	90.6	46.7	215
July	136	54.4	43.5	26.5	109.5
August	91.0	48.3	47.6	25.9	65.1
September	72.7	43.2	47.6	2.5	70.2
October	238	56.6	37.6	4.4	233.6
November	433	122	82.9	11.7	421.3
December	446	172	136	8.0	438
Year	218	152	145	100	118

Table 23. Variation of Monthly Discharges at Gauging Station 02HL004 on the Skootamatta River (1959-1969 data)

Month	Discharge in cubic feet per second (cfs)				
	Maximum	Mean	Median	Minimum	Range
January	362	171	139	14.3	347.7
February	363	197	172	18.0	345
March	747	393	377	153	594
April	2050	1010	843	525	1525
May	1120	480	419	179	941
June	268	147	134	54	214
July	193	55.5	25.5	10.8	182.2
August	60.6	18.4	14.2	6.3	54.3
September	67.1	27.6	16.6	5.5	61.6
October	430	90.6	43.0	5.9	424.1
November	792	242	154	12.2	779.8
December	920	319	240	20.0	900
Year	374	262	235	166	208

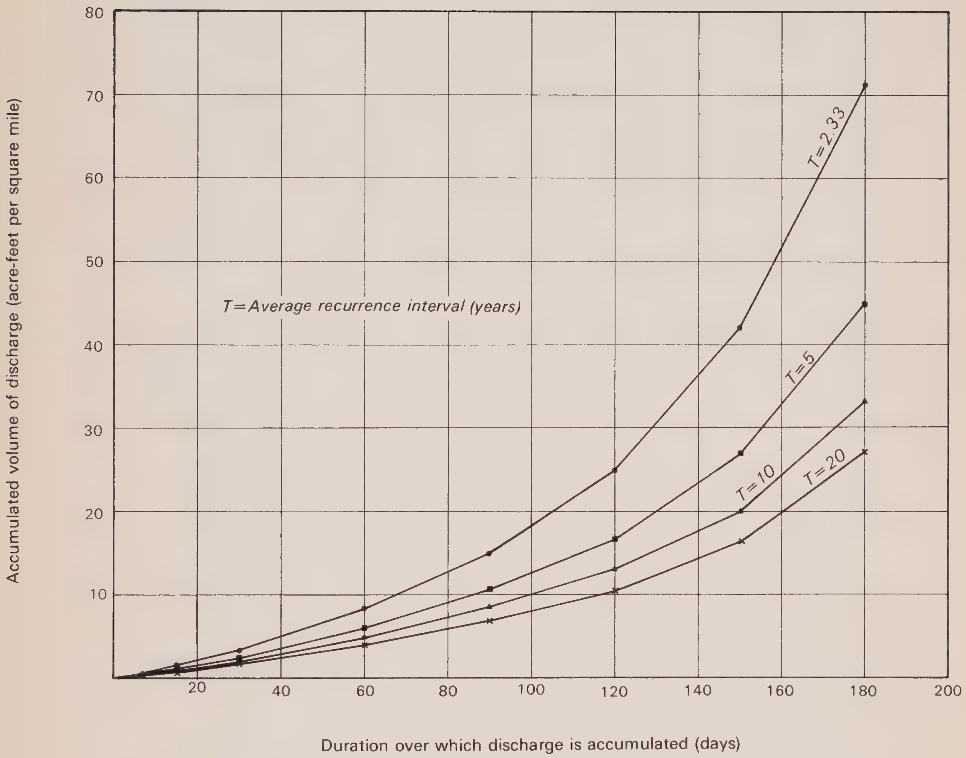


Figure 36. Low-flow frequency mass curves for gauging station 02HL001 on the Moira River near Foxboro (1916-1969 data).

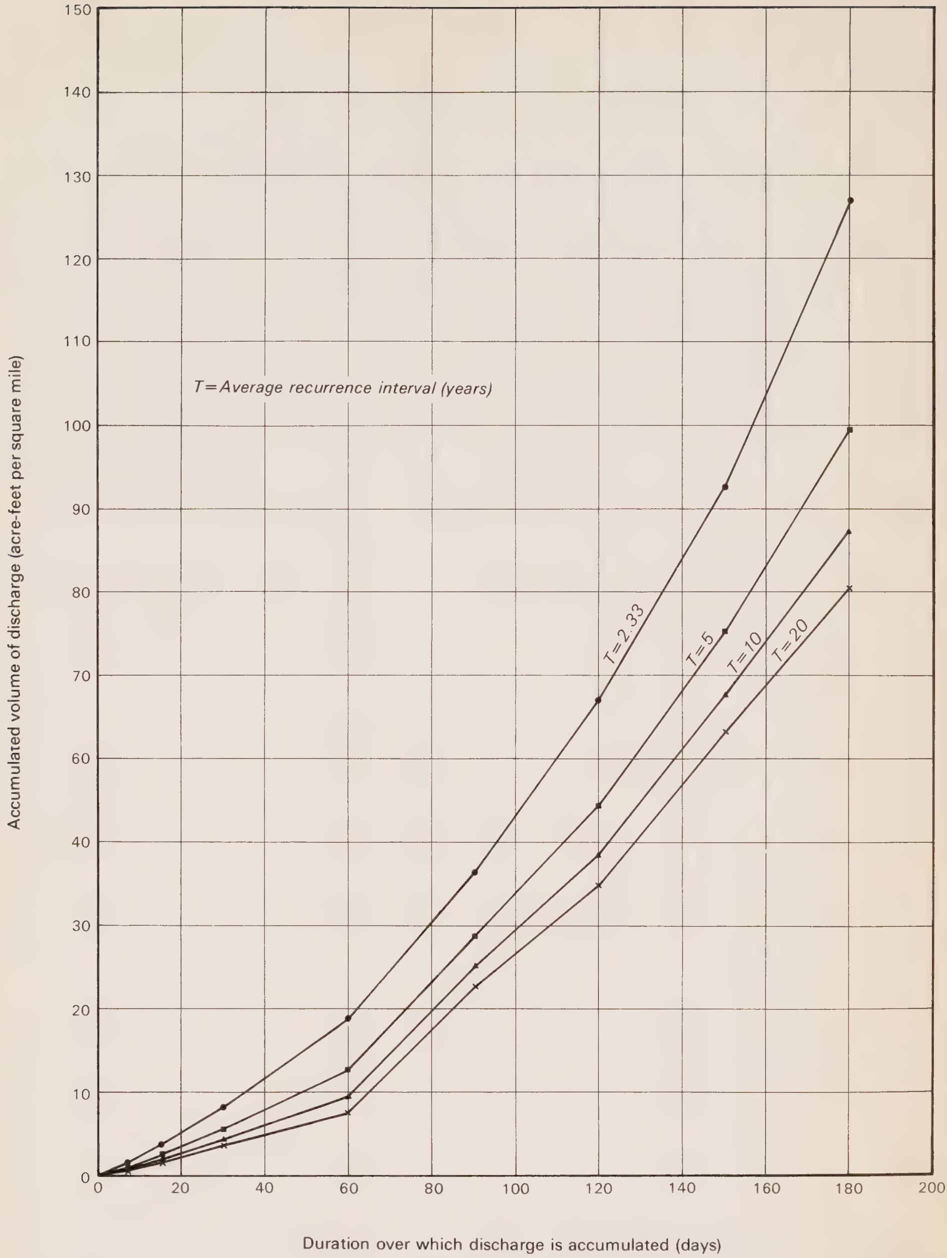


Figure 37. Low-flow frequency mass curves for gauging station 02HL003 on the Black River (1956-1969 data extended to cover the period 1916-1969).

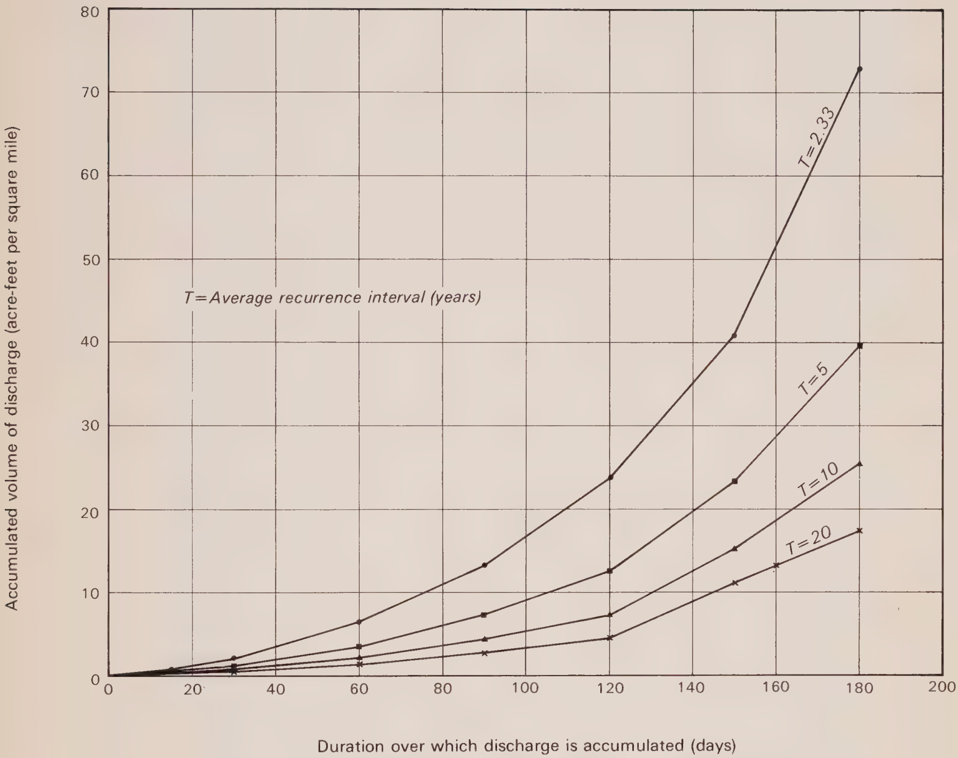


Figure 38. Low-flow frequency mass curves for gauging station 02HL004 on the Skootamatta River (1959-1969 data extended to cover the period 1916-1969).

LIBRARY
AUG 1976
UNIVERSITY OF TORONTO